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Petroleum Geology and Resource Assessment of the Middle Caspian Basin, USSR, with Special Emphasis on the Uzen Field

G. Ulmishek and W. Harrison

ARGONNE NATIONAL LABORATORY
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Energy and Environmental Systems Division
Applied Geoscience and Engineering Group

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CONVERSION FACTORS

Multiply	by	To Get
m	3.28	ft
km	0.621	mi
m^3	35.3	ft^3
t	1.10	short tons
m^3 oil	6.29	bbl
t oil[a]	7.40	bbl
kgf/cm^2	14.2	psi
m^3/t[a]	4.77	ft^3/bbl

[a]Assumes the oil has a density of 0.85 g/cm^3.

DEFINITIONS*

Discovered resources: Resources, and reasonable extensions thereof, whose location, quality, and quantity are known from drilling and geologic evidence, supported by engineering measurements.

Field: A field consists of a single pool (reservoir) or multiple pools (reservoirs) all grouped on, or related to, the same individual geological structural feature and/or stratigraphic condition. There may be two or more reservoirs in a field separated vertically by intervening impervious strata or laterally by local geologic barriers, or by both.

A new field is a discovery of oil or gas with accumulation being controlled by a separate geological structural feature and/or stratigraphic condition to the extent that the new discovery is not considered a new pool, or an extension of a pool, in a preexisting field.

Oil or gas in place: Concentrations or deposits of oil or natural gas that exist in nature and are defined to include all oil or gas in place without qualification as to what portion may be considered either currently or potentially extractable as a resource. Oil or gas in place refers to the estimated number of stock-tank barrels of crude oil or standard cubic feet of gas at 14.73 psia and 60°F in reservoirs prior to any production.

Pool: The term "pool" is often synonymous with the term "reservoir"; however, in certain situations, a pool may consist of more than one reservoir.

Reserve: That portion of the resource base from which a usable mineral and energy commodity can be economically extracted at the time of estimation. Such commodities include but are not necessarily restricted to petroleum, condensate, natural gas, tar sands, and naturally occurring asphalt, without regard to mode of occurrence.

Reservoir: A reservoir is a porous and permeable underground formation containing an individual and separate natural accumulation of petroleum confined by impermeable rock or water barriers and characterized by a single natural pressure system.

Resource: A concentration of naturally occurring solid or liquid petroleum or petroleumlike material, or natural gas, in or on the earth's crust, in such form that extraction is currently or potentially feasible. The resource includes all such material initially in place in a deposit.

Undiscovered oil or gas in-place: Undiscovered oil or gas in place is parallel in definition to undiscovered resources; that is, it refers to quantities of oil and gas estimated to exist outside of known fields on

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*These definitions are in current use by the U.S. Geological Survey (*cf*. 1980, pp. 9-10).

the basis of broad geologic knowledge. (In this report no qualification is made as to what portion is considered either currently or potentially economically extractable.)

Undiscovered pools that occur as independent accumulations controlled by separate geological structural features and/or stratigraphic conditions are considered in this study as separate deposits, even though they may occur beneath or above preexisting pools. They are not considered as part of future additions to known fields or as inferred reserves, but are estimated as a part of the overall undiscovered oil or gas in place.

Undiscovered resources: Resources surmised to exist on the basis of broad geologic knowledge and theory.

PETROLEUM GEOLOGY AND RESOURCE ASSESSMENT OF THE MIDDLE CASPIAN BASIN, USSR, WITH SPECIAL EMPHASIS ON THE UZEN FIELD

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ABSTRACT

The Middle Caspian Basin contains up to 12,000 m (40,000 ft) of sedimentary rocks ranging in age from late Paleozoic to Quaternary and has over 100 oil and gas fields varying in size from small to supergiant. The Soviet literature reviewed for this report covers: (1) tectonic zones of the basin, including details of the lower, intermediate, and upper structural complexes; (2) paleogeography, facies distribution, and conditions of organic matter accumulation in the major petroleum source rocks; (3) stages of oil and gas generation; (4) major hydrogeological features; and (5) producing regions of the basin. Total initial petroleum resources of the basin are estimated at 22.5×10^9 t (166×10^9 bbl),* of which 16.0×10^9 t (118×10^9 bbl) are yet to be discovered. Resources of the offshore Caspian Sea area are estimated to be 12.1×10^9 t (89.5×10^9 bbl). The most promising zones for offshore exploration are the plunging continuation of the Central Mangyshlak system of uplifts and the South Dagestan area. Initial reserves (oil in place) of the supergiant Uzen field are calculated to be 1.02×10^9 t (7.50×10^9 bbl). Because the recovery efficiency is estimated at 26-39%, recoverable oil is $0.261\text{-}0.397 \times 10^9$ t ($1.98\text{-}2.96 \times 10^9$ bbl). Analysis of the exploitation of the field shows significant difficulties related mostly to marked nonuniformity of reservoir permeability and to the high paraffin content of the oil.

EXECUTIVE SUMMARY

PURPOSE

This study, sponsored by the U.S. Geological Survey, is designed to: (1) provide a thorough review and assessment of Soviet literature on the petroleum geology of the Middle Caspian Basin; (2) estimate the petroleum resources of the basin; and (3) examine the past, present, and probable future petroleum production of the supergiant Uzen field, the basin's major accumulation.

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*Conversions from barrels to metric tons, and vice versa, assume an average crude oil density of 0.85 g/cm^3.

BASIN LOCATION

The Middle Caspian Basin is located mainly in the central part of the Caspian Sea, but also embraces the adjacent onshore areas of the Scythian plate on the west and the Turanian plate on the east (see Fig. 1). These two plates are part of the Epi-Hercynian platform, which includes large areas of western Siberia and the southern regions of the USSR. The South Caspian Basin, with its famous Baku petroleum region, is to the south of the Middle Caspian Basin. On the northwest, the Middle Caspian Basin is bordered by the East-European (Russian) pre-Cambrian platform. It is separated from the Volga-Ural region by the North Caspian (Peri-Caspian) depression with its strongly developed salt tectonics.

The Middle Caspian Basin includes two geographically and historically different areas -- the Central and Eastern Cis-Caucasus to the west of the Caspian Sea and the semidesert part of Western Kazakhstan to the east (see Fig. 2). Although the Eastern Cis-Caucasus (including the Northeast Caucasus) was one of the first oil-producing regions in Russia, the oil industry in the Asiatic part of the basin began to develop only in the last 20 yr or so.

TECTONIC SETTING AND STRUCTURAL COMPLEXES

The Middle Caspian Basin can be designated as a "petroliferous basin," to use terminology promulgated by Brod (1955). This term means a structural basin consisting of a central region of downwarping that is bordered by relatively uplifted structural units. The concept of a petroliferous basin permits a genetic investigation of the distribution of fields within the basin (Brod, 1964).

The central part of the Middle Caspian Basin is covered by the Caspian Sea. Eastern and western parts of the basin are situated on the Turanian and Scythian Epi-Paleozoic plates, respectively. To the southwest, the basin is confined by the Great Caucasus fold system; to the west, by the Mineralovod swell and the Stavropol arch. To the north, the basin's boundary runs along the Karpinskiy ridge; to the south, along the elevated Apsheron sill. To the northeast, the basin is contiguous with the North Ustyurt Basin and is separated from it by the Mangyshlak and Central Ustyurt zones of uplift where Permian-Triassic and Carboniferous rocks are exposed or occur close to the surface. Boundaries of the basin to the east are defined by the Tuarkyr uplift directly to the east of Karabogaz arch and the Shordzha transverse projection and Kumsebshen uplift on the eastern flank of the Central Ustyurt zone of uplifts and downwarps.

The boundaries of the basin differ in age of development. Structures on the north and east developed during Mesozoic and Cenozoic times. The southern border of the basin is related to development of the Great Caucasus Mountains. These mountains were a geosynclinal trough in the Mesozoic and early Tertiary, which was folded and uplifted beginning in the late Paleogene. This uplift gave a sharply asymmetrical form to the basin, with the axis of the deepest part close to the Great Caucasus Mountains. Gentle northeastern and steep southwestern slopes developed.

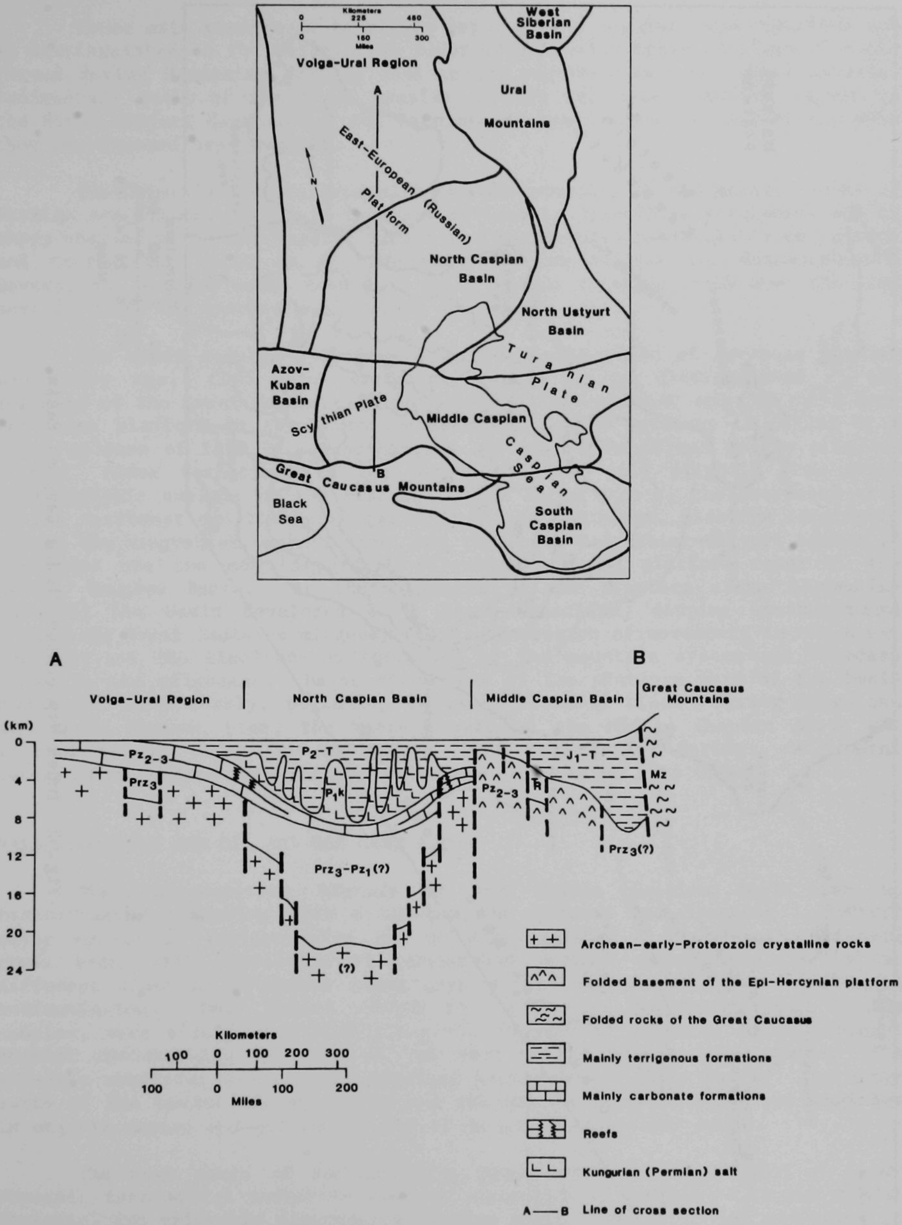

Fig. 1 Geologic Setting of the Middle Caspian Basin

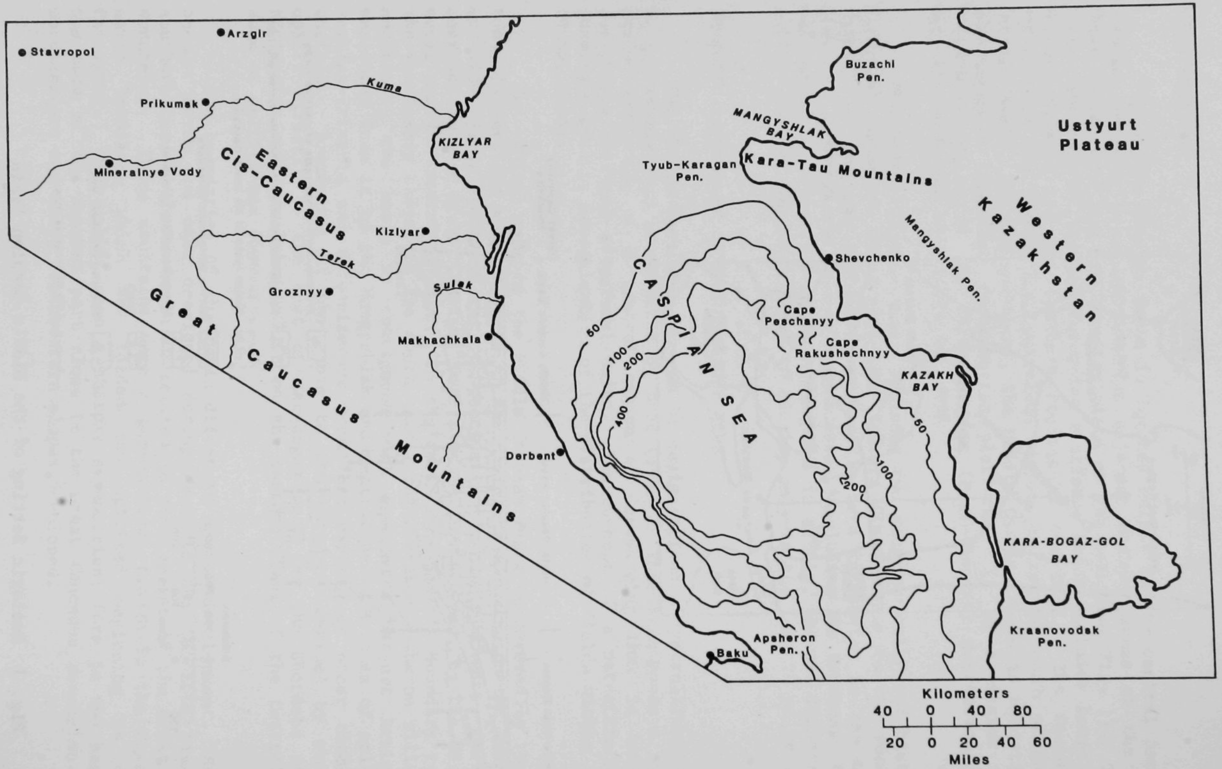

Fig. 2 Index Map of the Middle Caspian Basin

Three main structural complexes separated by angular unconformities can be distinguished in the basin. The lower (basement) complex consists of rocks formed during Hercynian folding that welded together ancient, rigid massifs. Sedimentary rocks of the lower complex usually are metamorphosed (except in the North Ustyurt depression) and intruded by igneous bodies, especially when they are located over massifs.

The intermediate (taphrogenic) complex consists of sedimentary rocks of Permian and Triassic age. It is characterized by grabenlike structures and by sharp variations in thickness. Except for the Central Mangyshlak zone, marine and terrestrial rocks of the intermediate complex are not metamorphosed. Several oil and gas pools have been found in the Triassic rocks over the last several years and intense exploration continues.

The upper complex (platform cover) includes rocks of Jurassic through Quaternary age. Two major structural units can be distinguished -- the foredeep of the Great Caucasus fold system on the southwest and the young Epi-Hercynian platform on the north and northeast. The foredeep is filled by a thick molasse of late Paleogene-Neogene age that pinches out on the platform slope. Older formations in the foredeep differ only slightly from their stratigraphic analogs on the platform. Two large arches, the Stavropol arch on the northwest and the Karabogaz arch on the southeast, plus the Karpinskiy ridge, the Mangyshlak meganticline, and the South Mangyshlak-Ustyurt system of downwarps are the most important structures of the platform cover of the Middle Caspian Basin. At the beginning of the platform stage (Jurassic-Eocene), the basin developed as a giant monocline, dipping southwestward toward the Great Caucasus miogeosyncline. Inversion of movements in the Great Caucasus and the simultaneous formation of the mountain system and foredeep began in the Oligocene. Major structures of the platform part of the basin developed continuously, beginning in early Jurassic time. During Oligocene and early Miocene time, the western part of the Middle Caspian Basin was covered by the thick (up to 1600 m [5250 ft]) Maykop Series. A general western inclination of structural surfaces occurred at this time.

PALEOGEOGRAPHY AND OIL AND GAS GENERATION

The sedimentation history of the Middle Caspian Basin can be reconstructed beginning with events in the Permian and Triassic. Several major cycles of sedimentation can be distinguished. The Permian-Triassic cycle began with deposition of terrestrial molasse that gradually and at different times in different areas gave way to marine clastic and carbonate sedimentation. Reef facies, which form the best reservoir rocks in the complex, were widely deposited along the borders of grabens. A significant angular unconformity is found at the base of the Norian Stage rocks. The directly overlying Triassic is composed mostly of volcanic rocks. The upper parts of the Lower Triassic rocks and the Middle Triassic rocks are enriched in organic matter and are considered to be potential source rocks.

The next cycle of sedimentation began with the deposition of Lower Jurassic terrestrial sediments over an unconformity surface. In the Middle Jurassic, two evidently disconnected marine basins existed in the geosynclinal trough and in the northern portion of the Eastern Cis-Caucasus. Terrestrial sedimentation on alluvial plains and in freshwater basins occasionally flooded by seawater predominated in other areas. A regional trangression followed by carbonate and clastic sedimentation took place during Late Jurassic time. The sea retreated at the end of this time (Tithonian Stage). A break in sedimentation and partial denudation of subjacent sediments can be seen in many sections. Only in the western portion of the foredeep was a residual basin preserved where more than 1000 m (3280 ft) of evaporites were deposited in Tithonian time. Middle Jurassic rocks contain 1.0-1.3% organic matter and are the major source of oil in this part of the sedimentary cover. Upper Jurassic evaporite and carbonate rocks form the regional seal that controls the distribution of pools in the subjacent sequence.

The Cretaceous cycle of sedimentation began with deposition of carbonate and clastic sediments of Neocomian age. This was followed by partial retreat of the sea in Barremian time. A thick, sandy, or clayey marine sequence, which is considered to be the major source for pools in the Cretaceous system, was deposited in the Aptian and Albian stages. Clastic sedimentation gradually gave way to deposition of predominantly carbonate rocks in Late Cretaceous time. This cycle culminated in retreat of the sea, which led to a regional break in sedimentation in Danian time.

The major paleogeographic feature of the Paleocene-early Miocene cycle of sedimentation was a large deep-sea basin in the area of the Cis-Caucasus and the modern Caspian Sea. The depth of this sea probably exceeded 1000 m (3280 ft). Foraminiferal limestones and highly bituminous clastic and carbonate rocks of the Kuma formation (upper Eocene) represent the deepwater facies. The deep basin was filled by the very thick (up to 1600 m [5250 ft]), mainly clayey Maykop Series (Oligocene-lower Miocene). This formation forms a regional seal of great importance for preservation of oil and gas in the underlying rocks. The Maykop Series is moderately enriched with organic matter (usually 0.5-0.8%), but conditions for migration of hydrocarbons were very poor. Nevertheless, Maykop shales are often considered to be source beds for the hydrocarbons occurring in subjacent Upper Cretaceous rocks. The cycle was terminated by a regional break in sedimentation between the early and middle Miocene. This break coincided with an important phase of structural deformation in the Middle Caspian Basin.

Rocks of the middle Miocene-Quaternary cycle of sedimentation are distributed mostly in the Great Caucasus foredeep, and their thickness in the foredeep exceeds 3000 m (9845 ft). The formations thin rapidly across the platform slope. Sediments of this cycle are represented by marine molasse overlain by a terrestrial and marine sequence of middle Pliocene-Quaternary age. The middle Miocene Chokrak and Karagan formations contain major oil pools in this part of the sedimentary cover and are believed to be source rocks.

Subsidence of source rocks to depths, where thermal conditions were favorable for the main phase of oil generation was not contemporaneous over the basin. The subsidence rate was highest in areas adjoining the Great Caucasus miogeosyncline and decreased to the north and northeast. Consequently, the major foci of oil generation were displaced during geological time in that direction. In the Middle Jurassic sequence, the main phase of oil generation in the foredeep terminated by the end of the early Miocene. Up to 900 x 10^3 t (6660 x 10^3 bbl) of liquid hydrocarbons had formed by this time in every column of Bajocian-Bathonian sedimentary rock having an area of one square kilometer. Later, the area of most intense generation moved from the platform slope northeast to the area beneath the modern floor of the Caspian Sea. Similar migration of the foci of generation is observed for the Aptian-Albian sequence. Large areas northeast of the Middle Caspian Basin have not yet undergone a main phase of oil generation. Generation of gas was more uniform. A major amount was generated in the Mesozoic sequence after deposition of the regional Maykop seal.

DEVELOPMENT HISTORY

The first well in the Middle Caspian Basin was drilled in 1893 near the city of Groznyy in the Starogroznenskoye field (see Fig. 3); oil was produced at a depth of 134 m (440 ft). The first oil from the South Dagestan region was obtained in 1901. Up to the end of World War II, exploration was concentrated in the Tertiary sequences of these regions, and a series of oil fields was discovered. By 1935 oil production had reached 1.0×10^6 t/yr (7.4×10^6 bbl/yr).

After World War II, exploration efforts shifted to the deeper Mesozoic sequences and to the new areas of the Stavropol arch and the platform slope of the Cis-Caucasus foredeep. The giant North Stavropol-Pelagiadinskoye field, with recoverable reserves of 220×10^9 m^3 (7.77×10^{12} ft^3) of gas, was found on the Stavropol arch. The first oil and gas field, Ozek-Suat in the Prikumsk region, was found in 1953. This discovery was followed by the opening of a series of new fields in Jurassic and Cretaceous sedimentary rocks at depths of about 3000 m (9900 ft). At the same time, several fields were found in the area of the Karpinskiy ridge. In 1950-1960 highly productive oil pools were discovered in Upper Cretaceous rocks of the old Terek-Sunzha and South Dagestan regions. Over the last several years, discoveries have become more and more infrequent, and the number of structures having exploration potential is now very limited. Annual production for this region reached a maximum of 18×10^6 t (130×10^6 bbl) in 1975. Production has since declined slowly to its present level of about $15\text{-}16 \times 10^6$ t ($110\text{-}120 \times 10^6$ bbl).

The oil and gas industry to the east of the Caspian Sea in the western part of Western Kazakhatan began to develop after important discoveries were made in 1959-1965. Several oil and gas fields were found at this time in the South Mangyshlak region (see Fig. 3), among them the large Zhetybay and the supergiant Uzen fields. Major producing horizons in these fields are in Jurassic reservoir rocks. Halbouty et al. (1970) estimated the recoverable reserves of the Zhetybay field at 149×10^6 t (1100×10^6 bbl) of oil and 31×10^9 m^3 (1.1×10^{12} ft^3) of gas. The reserves of the Uzen field were calculated at 493×10^6 t (3650×10^6 bbl) of oil. Although these estimates by American specialists are somewhat exaggerated (see Sec. 8.4), the fields of the South Mangyshlak region did create a basis for sharp increases in annual oil production, which exceeded 20×10^6 t (150×10^6 bbl) in 1975.

A limited number of geophysical investigations have been made on the large shelf of the central Caspian Sea. One field, Inchkhe-more, was found near Derbent. Several wells have been drilled over the last 10 yr on the Rakushechnoye-more structure near the shore of Mangyshlak; production here has been established from Triassic rocks.

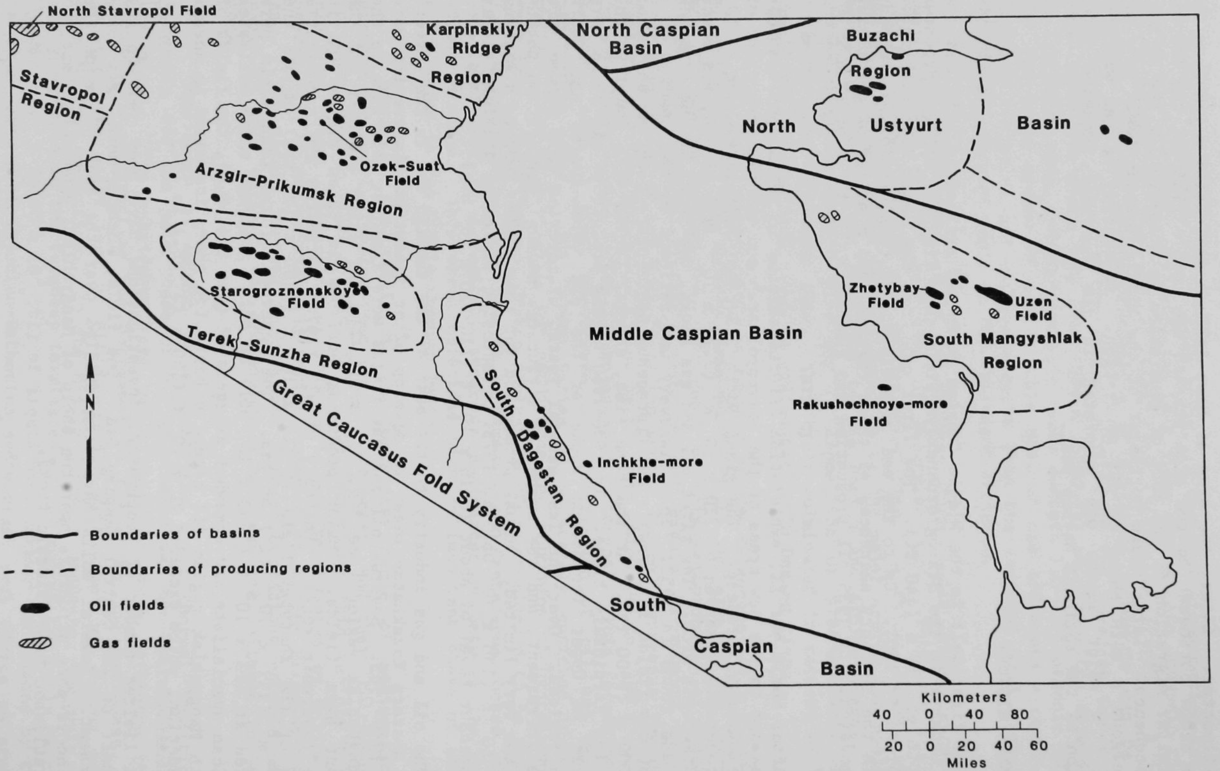

Fig. 3 Producing Regions of the Middle Caspian Basin

THE UZEN FIELD

The supergiant Uzen field was discovered in the South Mangyshlak region in 1961 and exploitation began in 1965. It is located on the Zhetybay step that complicates the northern slope of the South Mangyshlak trough. The step is characterized by an extremely high density of resources; almost all discovered oil and gas fields of the vast South Mangyshlak region are concentrated on this prominent structure. All of the productive strata on the step occur in Jurassic rocks. Although Lower Cretaceous rocks possess good reservoir properties, they are flushed by fresh water and do not contain pools.

The Uzen field is associated with a large anticlinal structure some 45 km (28 mi) long and 9 km (5.6 mi) wide. Strata on the northern flank of the structure dip 1.5-2°; dips on the southern flank reach 6-8°. The elongated western pericline is complicated by three subordinate closures. Some small faults have been recognized, which may affect the distribution of pools in the lowermost part of the sequence. Almost all reserves are concentrated in strata XIII-XVIII of the Callovian and Bathonian sequence. (See Fig. 50 for Roman numeral designations.)

Productive strata consist mainly of polymictic sandstones and siltstones enriched by clayey material and separated by shale layers. The strata display a complicated framework formed by irregular alternation of sandstones, siltstones, and shales. There are a varying number of sandy beds in each strata. Channel sandstones representing sediment deposited in ancient river valleys are found in strata XIII and XIV. The porosity of the sandstones is 18-23%. Permeability of the reservoir rocks varies widely and unevenly from a few to 1000 and more millidarcy (md), with the channel sandstones possessing the best permeability (usually more than 300 md). Oil pools in strata XIII-XVIII have a common oil-water contact and form one giant pool. Although the oil is undersaturated by gas, pools in strata XVI and XVII contain small gas caps. Reservoir pessures are 98-123 kgf/cm^2 (1390-1750 psi); the gas-oil ratio is 61-72.7 m^3/t (291-347 ft^3/bbl), and the density of stock-tank oil is about 0.85 g/cm^3 (35° API). The Uzen field oil is characterized by very high tar (9.7-21.1%) and paraffin (up to 28%) levels and relatively low sulfur content (0.1-0.24%). Stock-tank oil congeals at a temperature of 25-30°C (77-86°F). Calculated reserves (oil in place) are 1.02 x 10^9 t (7.50 x 10^9 bbl), with 64% of these resources contained in strata XIII and XIV (see Fig. 4).

Exploitation of the Uzen field has encountered significant difficulties because of: (1) the large area of the field, (2) the extreme heterogeneity of reservoir properties, (3) the high paraffin content, and (4) the closeness in values of reservoir pressure and saturation pressure. Emplacement of a system to maintain reservoir pressure caused a long delay; injection of hot water has not yet been accomplished for the planned volume. As a result, artificial gas caps have formed and precipitation of paraffin has reduced the permeability of the reservoirs, especially in the less permeable beds. Most production is obtained from beds with permeabilities greater than 300 md; beds with permeabilities of less than 150 md are almost unproductive. Since the injected water moves quickly through the highly permeable beds, intense watering-out of production is occurring. Evaluation of possible sweep efficiencies for reservoir rocks with differing permeability values permits calculating recoverable reserves at 25.7-39.1% of oil in place. The lower percentage is considered to be more probable. Achieving higher recoverability will require significant additional investment of equipment and labor.

RESOURCE ASSESSMENT

Producing regions of the Middle Caspian Basin are differentiated on the basis of structural, facies, and hydrogeological conditions; predominant producing formations; and types of traps. Some of the producing regions include unexplored offshore areas where geological features are presumed to be more or less identical to those found on land. Evaluation of the resource potential for the various regions of the basin was undertaken using three independent methods: volumetric, reservoir-volumetric, and volume-genetic.* The results of the three methods show good correspondence.

Initial petroleum resources in place of the Middle Caspian Basin are estimated at 22.5×10^9 t (166×10^9 bbl). Discovered resources are 6.5×10^9 t (48×10^9 bbl), and virtually all are located beneath the land surface of the basin (see Fig. 4). Undiscovered resources on land are small (3.9×10^9 t [29×10^9 bbl]) compared to offshore potential (12.1×10^9 t [89.5×10^9 bbl]) and were estimated using information on the degree of exploration in each of the producing regions.

The largest potential resources beneath the Caspian Sea are found in the South Mangyshlak region and are assumed to be as high as 4.9×10^9 t (36×10^9 bbl). The offshore region having the second highest potential is South Dagestan with resources estimated at 1.7×10^9 t (12.6×10^9 bbl). These two regions have been studied more than other areas beneath the Caspian Sea. Several excellent structural prospects are located in these two regions, and the first offshore field (Inchkhe-more) has been discovered. The plunging offshore continuation of the Mangyshlak system of uplifts, the Peschanomys arch, and the structures of the Maritime anticlinal zone offshore of South Dagestan will most likely be the first exploration objectives in the near future.

Geophysical investigation beneath other parts of the Caspian Sea has been rare and success probably lies several years ahead. Total in-place resources for the remainder of the offshore area are estimated at 2.8×10^9 t (21×10^9 bbl). A large portion of these resources is associated with sedimentary rocks occurring at great depths (5000-7000 m [16,400-22,950 ft] and more) and at water depths greater than 400 m (1310 ft).

Among the land prospects, only the Terek-Sunzha region possesses significant undiscovered resources (1.6×10^9 t [12×10^9 bbl]). However, these prospects are connected mostly with Lower through Middle Jurassic formations occurring at depths of 5000-7000 m (16,400-22,950 ft) in complicated geological conditions.

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*In the calculations, the oil equivalent for gas was taken to be 1 t of oil equals 1000 m^3 of gas.

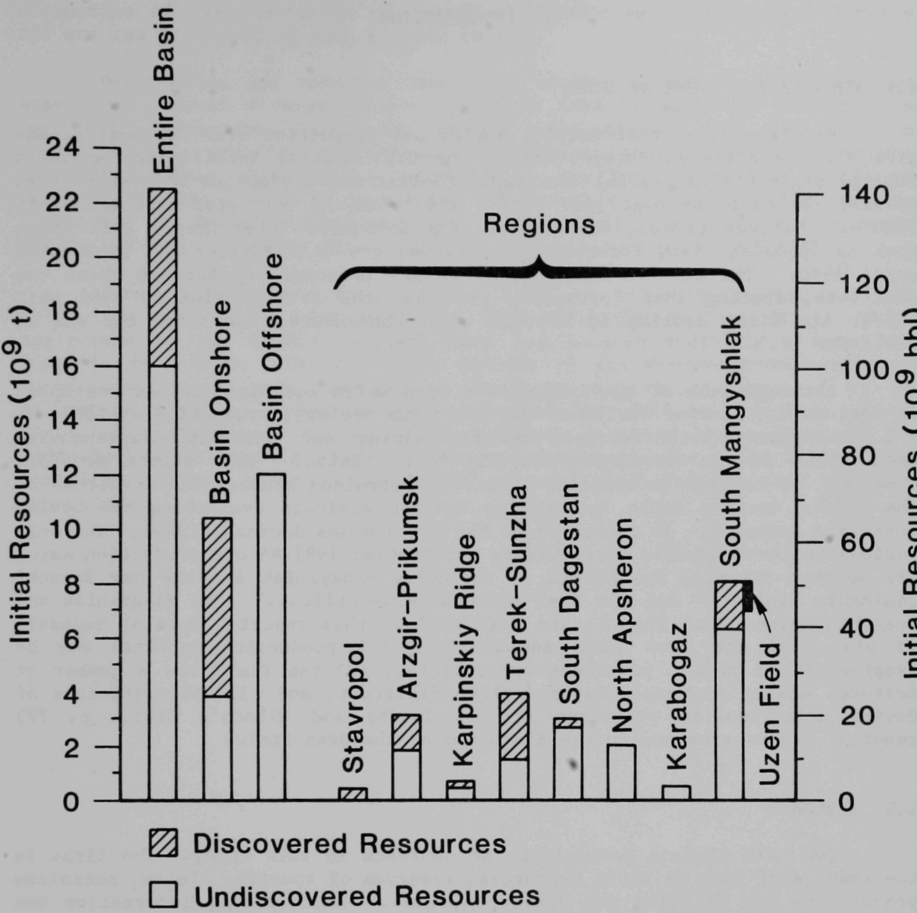

Fig. 4 Petroleum Resources of the Middle Caspian Basin and Its Producing Regions

1 INTRODUCTION

1.1 PURPOSE AND SCOPE OF STUDY

Recent studies that predict Soviet oil production over the next decade give sharply different projections. The U.S. Central Intelligence Agency's (CIA's) study (1977a, 1977b) declared: "Soviet oil production will soon peak, possibly as early as next year [1978] and certainly not later than the early 1980's." Wilson (1980), writing for The Economist Intelligence Unit Ltd., took an opposing view, forecasting continued growth in Soviet oil production until 1990. The Oil and Gas Journal (1980) is somewhere between these two positions, stating that "prospects are that the Soviet Union by 1982 will suffer its first decline in average crude/condensate flow since the end of World War II."

Although much of the information upon which such projections are based is derivative, careful review of the petroleum geology, production statistics, and development potential of specific basins can underpin comprehensive projections of oil production in the Soviet Union. This report provides thorough, up-to-date information about the petroleum geology and resources of the Middle Caspian Basin for use by Western analysts evaluating the Soviet petroleum industry. As indicated in the Oil and Gas Journal (1980), "The only regions believed capable of providing substantial 1981-85 oil production gains are western Siberia, Kazakhstan -- including Mangyshlak and the new Buzachi Peninsula fields -- and the Komi Autonomous Republic..." The Mangyshlak and Buzachi regions (see Fig. 2) are discussed in this report. Special emphasis is placed on the Uzen field because: (1) its production problems may be symptomatic of Soviet petroleum exploitation, (2) the field has a number of features making its exploitation rather difficult, and (3) CIA criticisms of Soviet waterflooding practices (1977a, 1977b) and Wilson's (1980, p. 77) rebuttal can be examined in the microcosm of the Uzen field.

1.2 APPROACH

Two main factors determined the approach to this study. The first is the absence of data on basin resources, reserves of specific fields, petroleum production, and drilling and discovery rates. Because this information has been classified secret by Soviet officials, the application of statistical methods to resource assessment is precluded. The second factor is the uneven study of the basin as a whole. More than half of the basin lies beneath the Caspian Sea. Because only a few regional seismic surveys have been run, extrapolations from land to sea (that is, from known to unknown) have been necessary. These extrapolations were used for all geological reconstructions as well as for resource assessments.

An analysis of the petroleum geology of the Middle Caspian Basin must begin with a review of the three major structural complexes: the lower complex, which consists of folded basement; the intermediate (taphrogenic) complex; and the platform cover. Tectonic zonation of these complexes and reconstruction of the structural development of the platform cover provide the basis for extrapolation of facies and hydrogeological conditions, and estimation of the quantities of dispersed organic matter and the volumes of oil and gas generated by such organic matter.

Description and resource assessment of the supergiant Uzen field was approached through a comprehensive review of data on reservoir properties of the rocks, effective thicknesses of the productive strata, properties of reservoir oil, and the geological framework of the anticlinal structure. Information from this review was used as the basis for calculating the reserves of the field. Assessment of possible recovery efficiency was approached via detailed consideration of the effectiveness of the exploitation system and water flooding from inception of exploitation through 1978.

Three independent methods were used to estimate resources. The volumetric method is considered the most reliable because it is widely applicable to the Middle Caspian Basin and because there is a reasonably adequate data base. The two other methods -- the reservoir-volumetric and volume-genetic -- were used as a check on the values obtained by the volumetric method. Resources were assessed for different regions of the basin, with separate figures for the offshore parts of the regions and for individual stratigraphic units. Resources unsuitable for exploration (those occurring in deep water or at depths of more than 7000 m) were evaluated separately.

2 STRUCTURAL COMPLEXES

2.1 OVERVIEW

The Middle Caspian Basin is filled by a thick (up to 12,000 m) sequence of sedimentary rocks varying in age from late Paleozoic (or perhaps from early and middle Paleozoic in the Ustyurt depression), to Quaternary. Lower, intermediate, and upper structural complexes are distinguished within this rock sequence.

The lower structural complex (basement) consists of ancient massifs and Hercynian structures. The intermediate structural complex is representative of the so-called intermediate stage. Definition of this stage has been discussed vigorously in the Russian literature of the last 10-15 yr. It is sometimes termed transitional, taphrogenic (after G.M. Kay), epigeosynclinal, or quasi-platform. Despite divergence of opinion, the intermediate stage generally is understood as a specific stage of tectonic development after an orogenic phase of geosynclinal deformation and before a platform stage of relative stability. It is characterized by progressive uplift inherited from the orogenic phase and by the formation of grabenlike troughs filled with essentially molasse sediments. The platform stage of the Middle Caspian Basin began in the Early-Middle Jurassic; sedimentary rocks of this stage form the upper structural complex.*

The intermediate complex includes sedimentary rocks of late Permian and Triassic age on the Scythian and Turanian plates. Although the Rhaetian-Lower Liassic sequence is usually grouped with the intermediate complex, its placement is somewhat unclear. Placement of the lower boundary of the intermediate complex in the upper Paleozoic internal downwarps also is somewhat artificial. Paleozoic rocks in these zones all have the same character; they are unmetamorphosed to weakly metamorphosed. Large-scale structural discordance between the two complexes is absent. Relationships of this kind are typical of the North Ustyurt depression and may also occur at great depths in the central part of the South Mangyshlak trough. From the standpoint of petroleum geology, there are no important differences between the intermediate and upper Paleozoic complexes, and both are interesting targets for exploration.

2.2 LOWER STRUCTURAL COMPLEX

Two main types of internal structures occur in the basement of the Middle Caspian region (see Fig. 5). The first type is ancient, rigid massifs, probably dating from the time of the Baykalian (pre-Paleozoic) consolidation. These are the Karabogaz and South Cis-Caucasus massifs. To judge from the sparse drill-hole data and rare exposures, the massifs consist of moderately

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*The upper structural complex is often referred to as the platform cover. This term is used in this report even though it is not perfectly accurate for the whole basin, because the basin data include a foredeep. However, all formations of the upper structural complex (except for the late Cenozoic molasse in the foredeep) are of the same type as those on the platform and were deposited under essentially platform conditions.

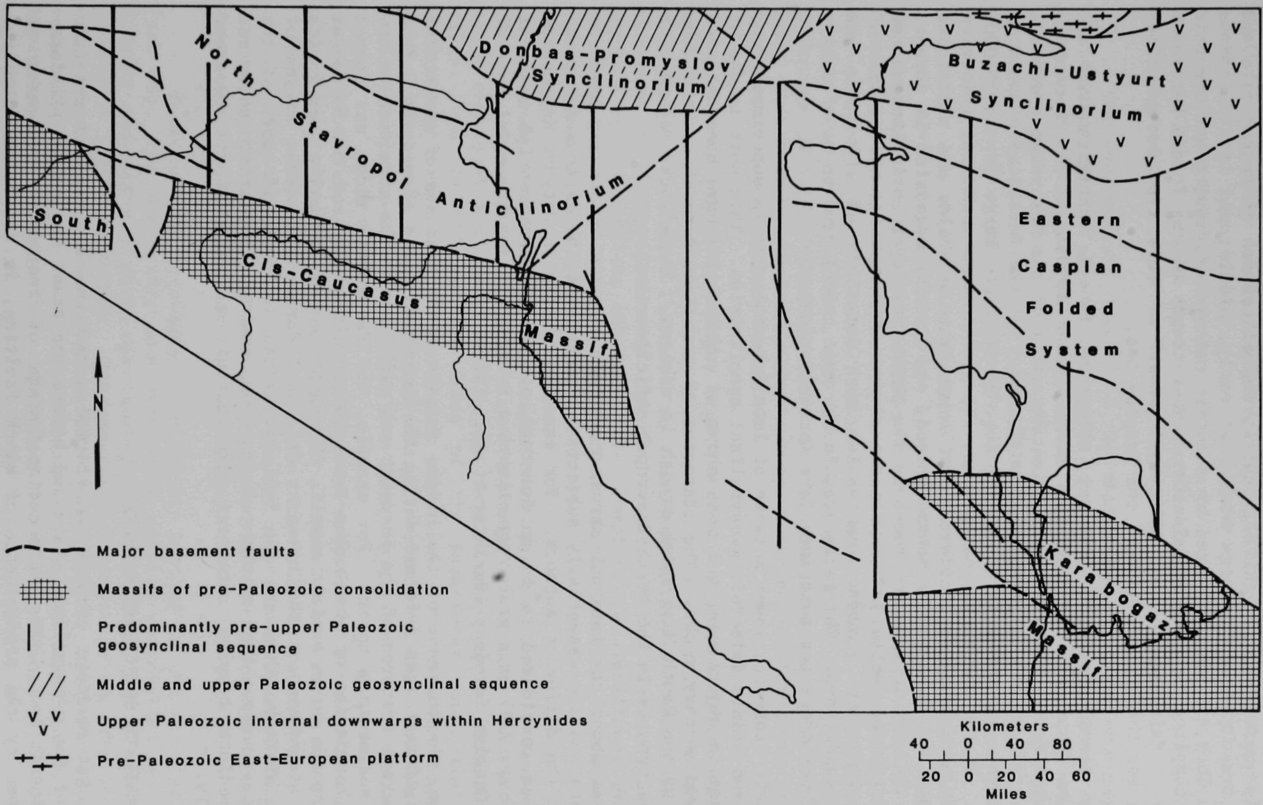

Fig. 5 Major Tectonic Elements of the Folded Basement (Source: Modified from Krylov, 1971)

to strongly metamorphosed schists, shales, and siltstones of Proterozoic and Paleozoic age intruded by large bodies of early, middle, and late Paleozoic granites. They are characterized by a mosaic pattern of gravity and magnetic fields as compared to the predominantly linear trends of the folded Hercynian structures. Existence of an additional massif of this type is sometimes postulated for the central part of the Caspian Sea.

The second type of internal structure is the anticlinorium and synclinorium recognized in the area of Hercynian folding. The former is characterized by relatively thin sedimentary units of the Hercynian cycle and by evidence of granite magmatism. The thickness of the Hercynian complex in the Donbas-Promyslov synclinorium (see Fig. 5) is quite large (up to 15,000-20,000 m). At the end of Paleozoic time, the synclinorium underwent inversion and intense folding. Carboniferous and lower Permian shales and siltstones are deformed but only weakly metamorphosed, and granite magmatism is absent. The upper beds of sedimentary rocks in the North Stavropol anticlinorium are penetrated by many wells. The beds are always metamorphosed and consist of deformed, dark-gray, carbonaceous shales with interbeds of siltstones and quartzitic sandstones. The rocks are, in the main, considered to be of early-middle Carboniferous (or sometimes late Carboniferous) age.

A late-orogenic, lower molasse of late Paleozoic age is superimposed on the early and middle Paleozoic geosynclinal synclinorium. This unit is one of the exploration objectives, and some shows of oil and gas have been detected in these sedimentary rocks. The character of pre-upper Permian rocks in the deep part of the South Mangyshlak trough is unknown. These rocks may well be of the same type as in the North Stavropol anticlinorium.

Ideas about the internal structure of the basement rocks are based on limited data and are essentially subjective, reflecting the various interpretations of the different authors. For example, the North Ustyurt depression is sometimes considered to be an internal massif with Precambrian basement (Sapozhnikov, 1978) or a graben-synclinorium is presumed for the axial part of the Terek-Caspian foredeep (Burshtar et al., 1972).

Thus, the basement of the Middle Caspian Basin consists of structural units of different ages deformed during the Hercynian phase of orogeny. Some of the internal features of the basement are reflected in the structure of the overlying sedimentary cover. For example, the Karpinskiy ridge was formed along the boundaries of the Donbas-Promyslov synclinorium, and the Karabogaz arch corresponds to an ancient massif. Although some of the major deep faults and other structures of the basement developed during subsequent stages of geological history, they are not fully reflected in the upper part of the geological sequence. Most of the younger structures of the platform cover and the intermediate complex intersect the tectonic elements of the basement discordantly.

2.3 INTERMEDIATE STRUCTURAL COMPLEX

The intermediate complex was formed after the folding and granitic magmatism of the geosynclinal stage and before the onset of typical platform-cover sedimentation. The intermediate stage of tectonic development is distinguished by the predominance of block faulting, in comparison with the alpinotype folding found in geosynclines or the sloping dislocations of the platform type. Consequently, the main structures are grabens and grabenlike troughs (taphrogens), which are often associated with faults of the previous stage and, to a lesser extent, isometric depressions. Effusive rocks are usually present.

The intermediate complex of the Middle Caspian Basin encompasses rocks of late Permian and Triassic age and consists of two structural units. The lower unit includes Permian and Lower and Middle Triassic terrigenous and carbonate beds, while the upper unit is represented by a volcanic-sedimentary sequence of late Triassic age (Norian), which nonconformably overlies different horizons of the underlying sequence or, less often, basement rocks.

The main tectonic elements of the intermediate complex in the Middle Caspian Basin are shown in Fig. 6. Principal elements of the Eastern Cis-Caucasus include the East Manych and Arzgir taphrogens, both of which are bounded by large faults. They are separated by a narrow swell with an amplitude of several hundred meters. The thickness of the intermediate complex reaches 2000-3000 m here and increases to the east. The East Manych taphrogen probably connects with the Mangyshlak system under the Caspian Sea. On the north and south, the taphrogens are bordered by steps with lesser thicknesses of sedimentary rocks.

The so-called Kuma-Nogay zone (see Fig. 6) occurs to the south of the taphrogens and consists of several uplifted and relatively subsided parts separated by faults. The zone is characterized by a reduced intermediate sequence, by disappearance of the middle part of the sequence, and on high uplifts by the complete absence of the complex. A significant part of the complex, especially in the eastern portion of the zone, is formed by the upper volcanic-sedimentary formation.

Fault tectonics is less significant for the Berezkin depression (see Fig. 6). Geophysical evidence places the southern boundary of the depression along the Terek anticlinal zone in the Terek-Sunzha region (Burshtar et al., 1972). As in the eastern areas of the Kuma-Nogay zone, the volcanic-sedimentary rocks form a substantial part of the intermediate complex. The depression opens into the Caspian Sea and probably extends to the Karabogaz arch, where volcanic rocks of the same kind are present in its northern part.

To the east of the Caspian Sea, the sequence of Permian-Triassic age is more widespread and thicker. Major structures in this region are the Central Mangyshlak and Beke-Bashkuduk taphrogens, in which the intermediate complex is up to 9000 m thick. In contrast to all other structures of this tectonic stage, the Central Mangyshlak and Beke-Bashkuduk taphrogens underwent post-Triassic/pre-Jurassic inversion and folding.

Rocks of the intermediate complex are exposed in the Kara-Tau Mountains (see Fig. 2), where they are profoundly changed epigenetically, have high density and, from a petroleum geology point of view, may be considered as forming a folded basement. Permian-Triassic rocks in the Chakyrgan horst, which separates the two above-mentioned taphrogens, have the same type of epigenetic features. A distinctive feature of the taphrogens is the thick Upper Triassic sequence that is absent in adjacent areas. From the Jurassic

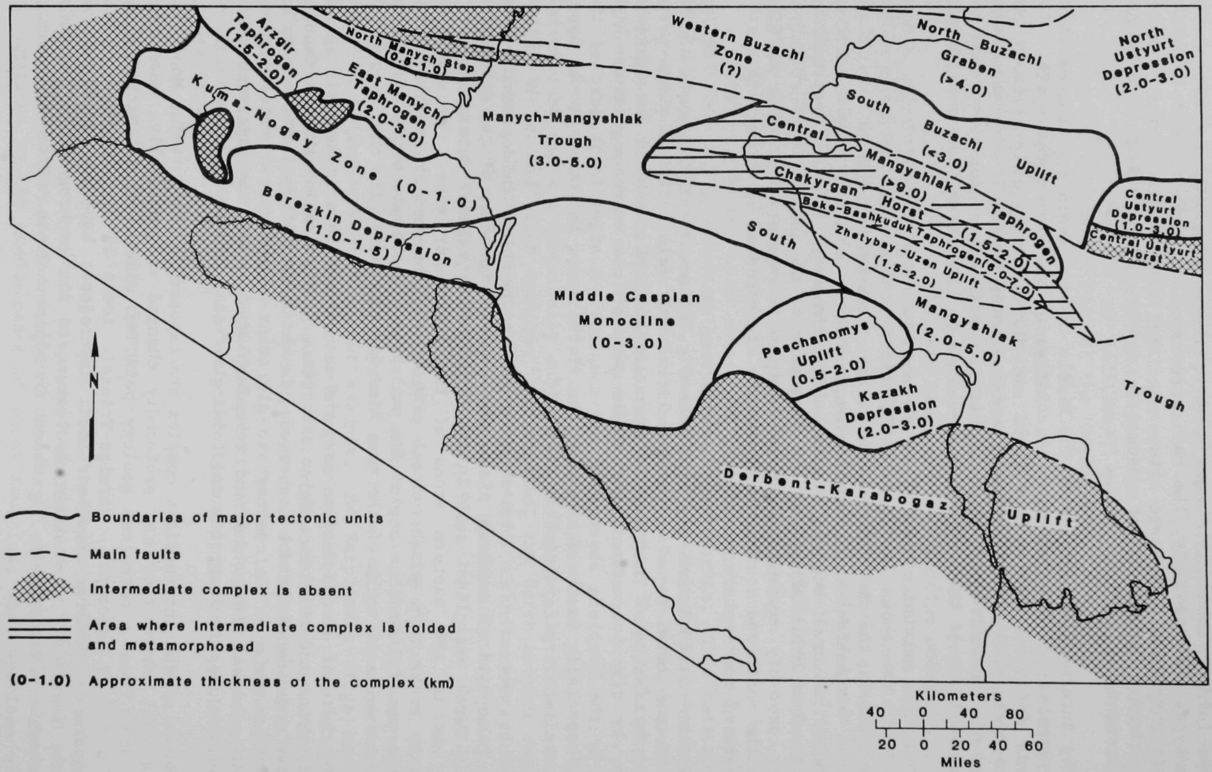

Fig. 6 Major Tectonic Elements of the Intermediate Complex (Source: Compiled from Letavin, 1978)

onward, the taphrogens developed as large swells; an elongated trough was formed under the Chakyrgan horst.

A thinner sequence of formations of Permian-Triassic age characterizes the Zhetybay-Uzen uplift to the south of the Beke-Bashkuduk taphrogen. The uplift extends for more than 250 km and has a width of about 30 km. A deep fault separates the uplift from the South Mangyshlak trough, where the intermediate complex occurs at great depths; its structure is almost unknown.

To the north of the Central Mangyshlak taphrogen, thicknesses of the intermediate complex reach 2000-4000 m. Block dislocations do not play an important role here. Sedimentary beds are mainly horizontal. The greatest thicknesses are found in the North Buzachi grabenlike depression. About 2000 m of these rocks are penetrated by a well in the western part of the peninsula.

The Central Ustyurt horst is a sharply elevated structure located between the northern Ustyurt and Mangyshlak regions. Here, Jurassic rocks overlap Carboniferous folded and metamorphosed rocks.

Structural features of the intermediate complex in the Central Caspian Sea must be inferred from scanty geophysical data. The southern part of the offshore region is occupied by the northerly dipping Middle Caspian monocline. The Peschanomys uplift (see Fig. 6) is a structural nose that separates this zone from the Kazakh depression on the southeast. The system of taphrogens and uplifts of central Mangyshlak can be traced offshore for a distance of 60-80 km. It then merges to a single trough, which connects with an offshore continuation of the East Manych taphrogen.

Only some of the regional structures of the intermediate complex are inherited by the upper platform cover. For example, overlying the East Manych and Arzgir taphrogens is the East Manych Mesozoic depression. Other structures thought to have influenced the upper platform cover are the Peschanomys uplift and the Kazakh depression. Also, the taphrogens and uplifts of Central Mangyshlak are reflected in the post-Triassic sedimentary cover as inversional structures. As a rule, however, local structures in Jurassic and overlying sedimentary rocks are discordant with structures of the intermediate complex. Typical examples of such discordance are shown in Fig. 7. Sometimes, especially in the Eastern Cis-Caucasus, local structures in the Permian-Triassic sequence coincide with crests, flanks, or periclines of brachyanticlines in the platform cover (Kopylov et al., 1977). Thus, the Jurassic-Cretaceous structural framework cannot consistently serve as a basis for drilling for deeper Triassic objectives.

2.4 UPPER STRUCTURAL COMPLEX

Two main tectonic regions can be distinguished in the Mesozoic-Cenozoic cover of the Middle Caspian Basin. The foredeep of the Great Caucasus fold system (see Fig. 8) occurs in the southwestern portion of the Middle Caspian Basin, whereas a young Epi-Hercynian platform is present in the northern and northeastern portions.

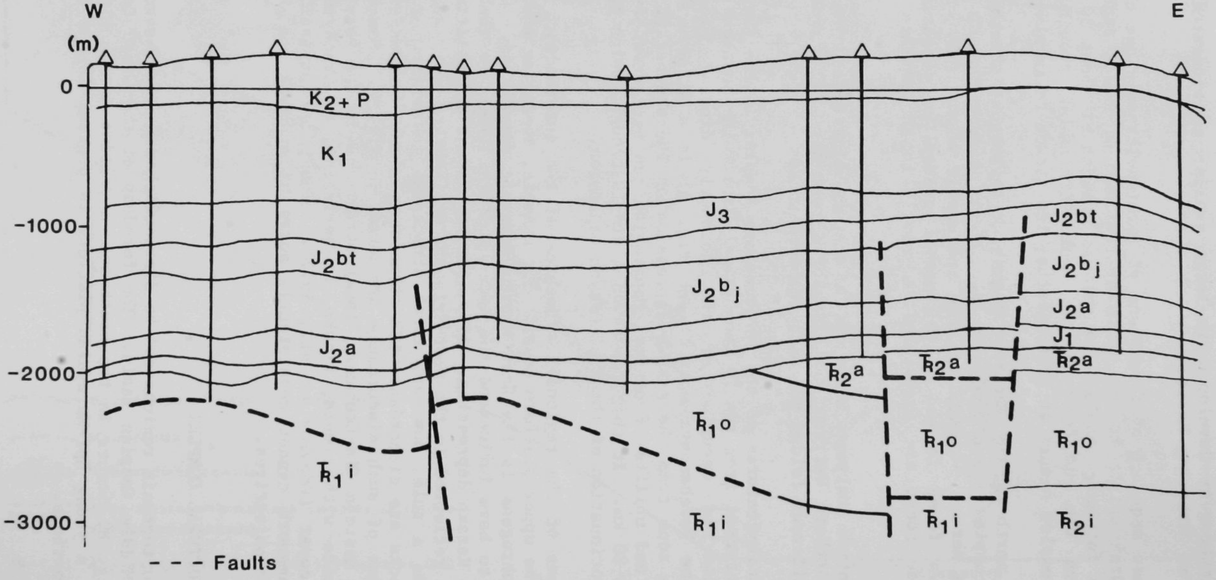

Fig. 7 Cross Section along the Uzen Field, South Mangyshlak Region (Source: After Stasenkov et al., 1977a)

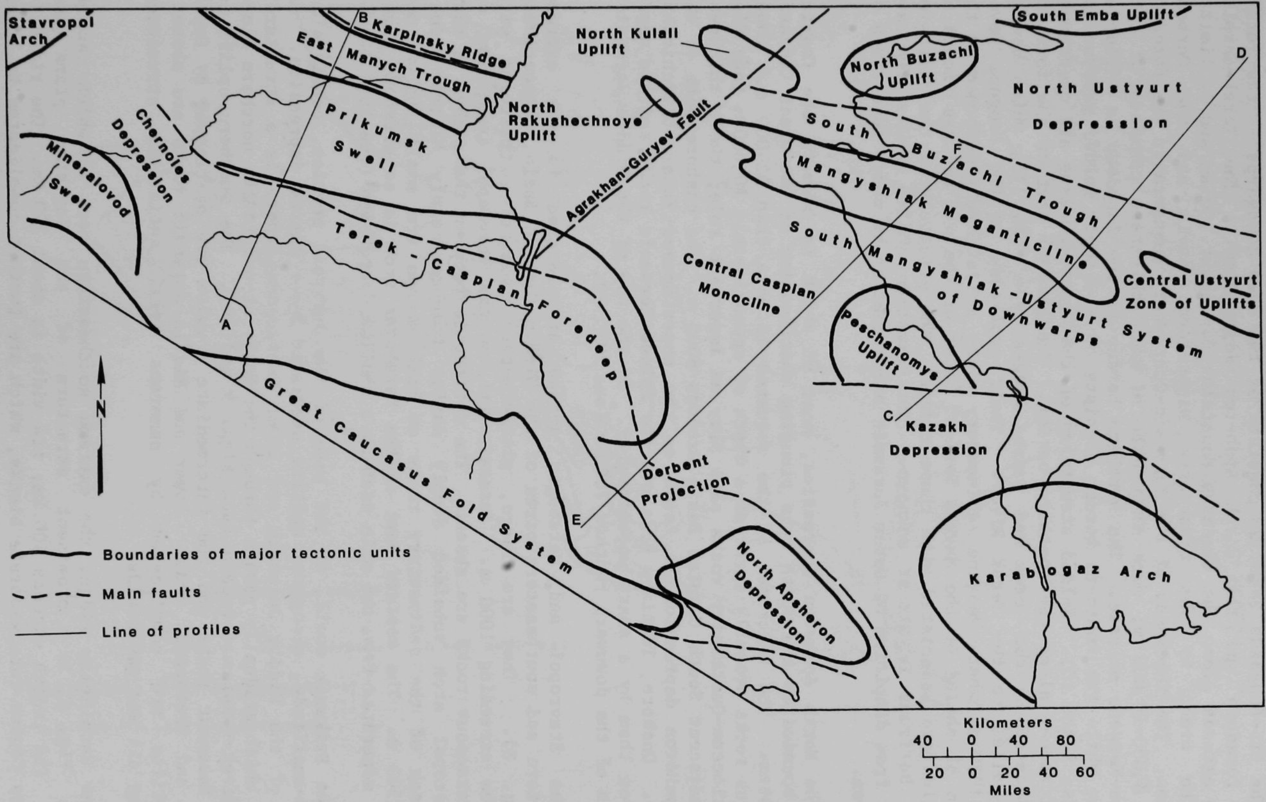

Fig. 8 Major Tectonic Elements of the Platform Cover

The Cis-Caucasus foredeep consists of two deep downwarps -- the Terek-Caspian foredeep and the North Apsheron depression. The Terek-Caspian foredeep extends along the Caucasus Mountains for about 500 km and is limited along the trend by the transverse Mineralovod swell and the Derbent projection. The thickness of the Jurassic-Quaternary sequence in the foredeep reaches 8,000-10,000 m; more than half of this thickness consists of late Paleogene-Neogene molasse. The northern border of the foredeep is a sloping platform, while the southern border consists of a steeply folded geosyncline (see Figs. 9 and 10). Folded structures of the Great Caucasus are overthrust on the foredeep along the southern border. The central part of the foredeep is complicated by the Terek and Sunzha Ridges (see Fig. 11), which have a trend parallel to the Terek River. Their amplitude at the Neogene level reaches 1000 m, where Neogene sedimentary rocks are strongly deformed by the diapirism of shales of the Maykop Series. Most of the oil and gas fields of this region are associated with these ridges. The structure of the ridges on Jurassic horizons is almost unknown. The formation of the ridges may have resulted from diapirism of Upper Jurassic halogenous rocks under conditions of compaction.

The North Apsheron depression, most of which is beneath the Caspian Sea, is bounded on the south by a plunging continuation of the Great Caucasus fold system. The thickness of the sequence is more than 12,000 m. Lower Cretaceous rocks probably occur at a depth of approximately 10,000 m (see Fig. 10). Pliocene-Quaternary rocks also play an important role; their thickness in the adjacent South Caspian Basin exceeds 8000 m. The onshore part of the North Apsheron depression is known as the superimposed Kusaro-Divichinskiy downwarp. Onshore, Tertiary beds overlie folded Mesozoic rocks and are separated from them by a sharp unconformity. On the top of the Middle Jurassic, the depth of the downwarp reaches 7000 m (see Fig. 9).

The Stavropol and Karabogaz arches are located in the extreme northwestern and southeastern parts of the Middle Caspian Basin, respectively (see Fig. 8). They are large, platform-type isometric structures with amplitudes exceeding 1000 m. Jurassic and, on the Stavropol arch, most of Lower Cretaceous rocks are absent. The difference between the arches is that the Stavropol arch subsided deeply during Paleogene-early Miocene time. Thicknesses of the sedimentary rocks on both arches are small and do not exceed 1500 m. The western part of the Karabogaz arch is an offshore high, which is separated from the main arch by a shallow depression (see Fig. 10).

The Prikumsk swell, at the base of the Jurassic section, consists of two, low-amplitude, elongated uplifts separated by a narrow depression. At the top of the Middle Jurassic and Lower Cretaceous, there is a structural terrace, which gradually passes through the Nogay step into the northern slope of the Terek-Caspian foredeep (see Figs. 9 and 10). The southern uplift is older. Basement rocks and the intermediate complex are overlapped by Upper Jurassic and Cretaceous beds. Lower and Middle Jurassic rocks are absent. Both uplifts are complicated by numerous local anticlinal structures containing oil and gas fields.

The Karpinskiy ridge, the extreme southeastern part of which can be seen in Fig. 8, is a prominent structure of the Scythian plate (see Fig. 1). Its length exceeds 500 km; its width is about 150 km. The ridge is broken by faults into separate blocks, which are further complicated by local

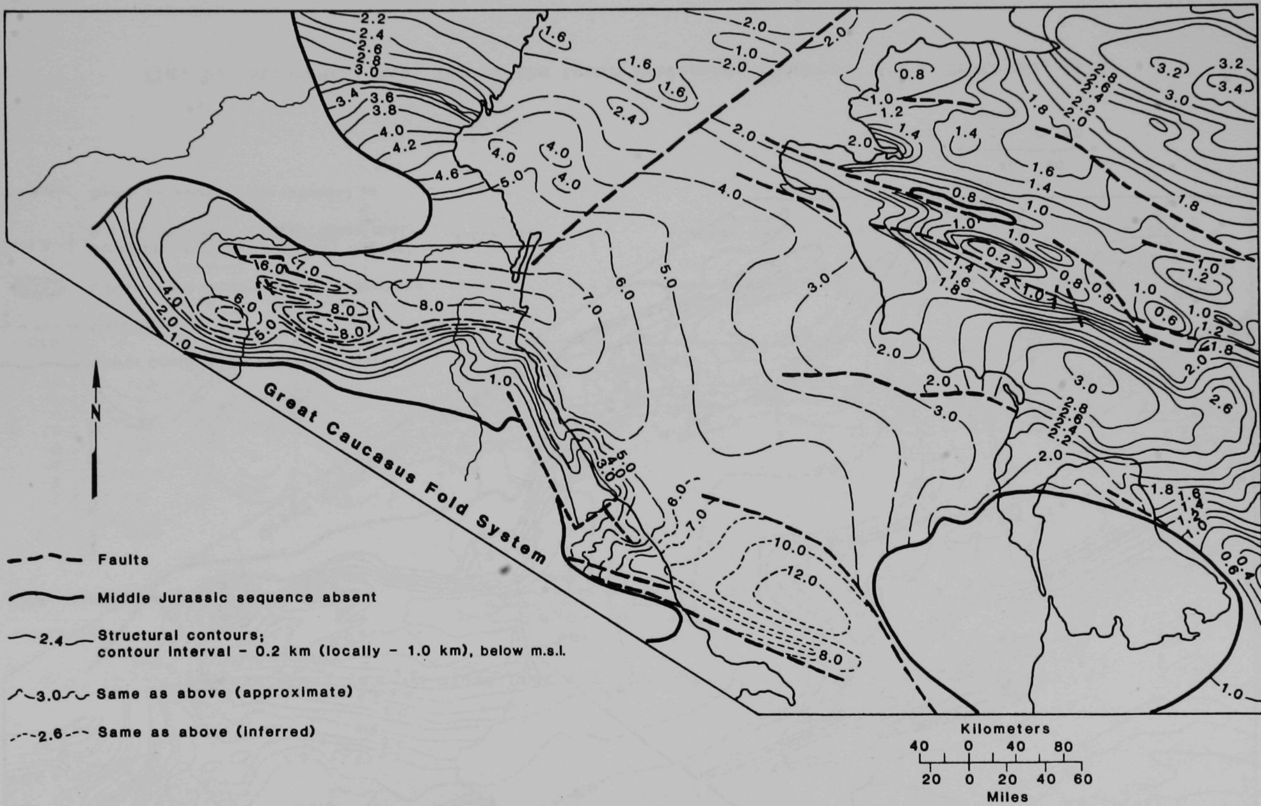

Fig. 9 Structural Map, Top of the Middle Jurassic (Source: After Trotsyuk, 1978)

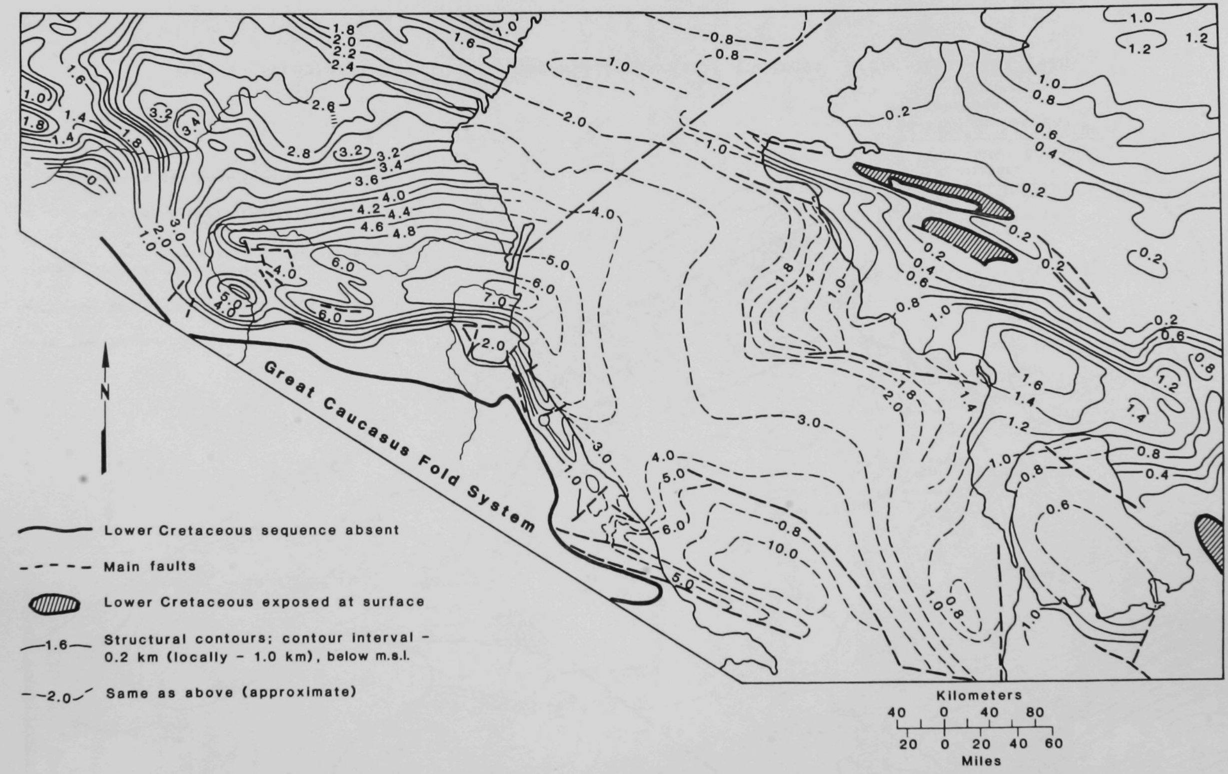

Fig. 10 Structural Map, Top of the Lower Cretaceous (Source: After Trotsyuk, 1978)

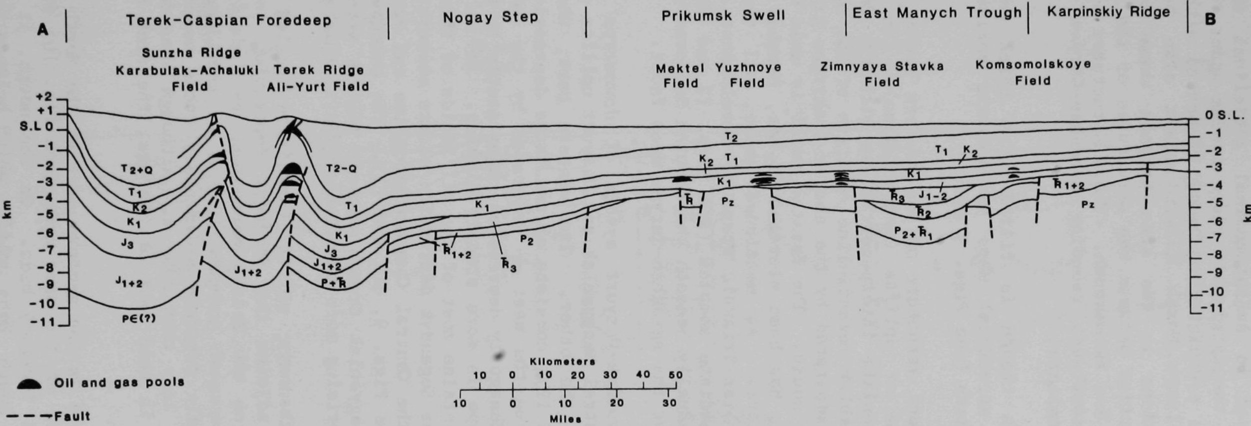

Fig. 11 Geological Cross Section along Line A-B (see Fig. 8) (Source: After Dikenshtein et al., 1977)

brachyanticlines grouped in sublatitudinal anticlinal zones. Geophysical evidence suggests that the Karpinskiy ridge trends under the Caspian Sea, and the ridge is sometimes postulated as being connected with the North Buzachi uplift. While the large North Kulali uplift also has been placed by geophysical investigations in the area between these two structures, the character of the connection between the structures of the western and eastern shores of the Caspian Sea is unknown. These structures are separated by the large, northeast-to-southwest trending Agrakhan-Guryev fault, along which many structures are terminated.

The East Manych trough is filled by a thick sequence of beds of Permian-Triassic age; structural maps on Mesozoic horizons show a terrace slope dipping to the south (see Figs. 9 and 10).

The most prominent structure on the eastern border of the Caspian Sea is the Mangyshlak zone of uplifts (meganticline). On the east end, the meganticline has echelonlike interpenetrations with the Central Ustyurt zone of uplifts. The Mangyshlak meganticline consists of two swells: the Karatau swell on the north is separated by the narrow Chakyrgan trough from the Beke-Bashkuduk swell on the south. The Karatau swell is made up of several large anticlines. Because it has been elevated higher, Permian and Triassic rocks are exposed in its core. As mentioned above, all three structures are inherited from the Permian-Triassic stage of development and are inverse in relation to the intermediate complex (see Figs. 12 and 13). The Mangyshlak meganticline slopes gradually beneath the Caspian Sea over a distance of about 60-80 km and closes near the Agrakhan-Guryev deep fault.

The South Mangyshlak-Ustyurt system of downwarps (see Sec. 7.1) is located between the Central Mangyshlak and Ustyurt uplifts on the one side and the Karabogaz arch on the other. Its western part, the South Mangyshlak trough (see Figs. 8 and 12), consists of two large depressions -- Zhazgurly on the east and Segendyk on the west -- separated by the Karagii saddle. The southern slope of the Zhazgurly depression rises gently to the Karabogaz arch, while the northern slope is more steeply dipping. It is complicated by the Zhetybay step, which contains most of the oil fields of this region. Only the very eastern part of the Segendyk depression occurs onshore; the major portion gradually passes into the Central Caspian monocline and occupies a large part of the Caspian Sea (see Figs. 9, 10, and 13). The thickness of the platform cover in the South Mangyshlak trough exceeds 5000 m with the Jurassic and Cretaceous section comprising more than two-thirds of this platform cover.

The large Peschanomys uplift (sometimes called the Peschanomys-Rakushechnoye uplift) adjoins the Segendyk depression to the south. The uplift is separated from the Kazakh depression by a deep-seated fault (see Fig. 12), whose displacement exceeds 1000 m in the Jurassic horizons and decreases upward. Middle Jurassic sedimentary rocks occur along the top of the arch at a depth of less than 2000 m. Although considered to be a prime target for exploration in this part of the sea, the arch has proved to be a disappointment.

The main structure in the western part of the North Ustyurt Basin is a large, gentle depression of the same name (see Fig. 10) filled by more than 4000 m of Mesozoic and Tertiary beds. On the north, it is separated by a deep fault from the South Emba uplift, which belongs to the East-European

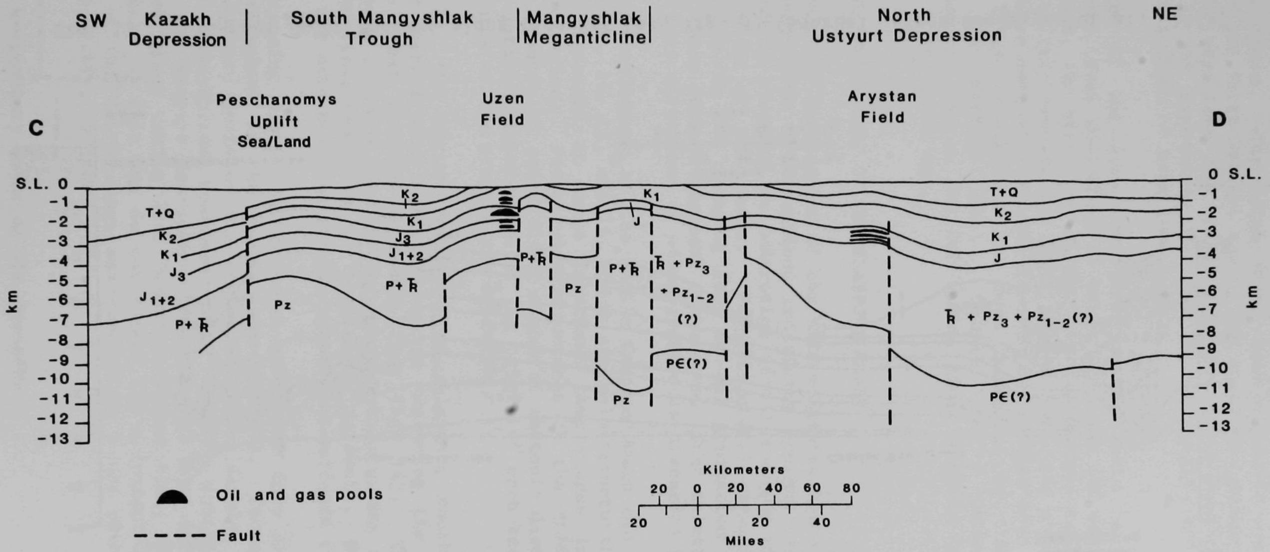

Fig. 12 Geological Cross Section along Line C-D (see Fig. 8) (Source: After Dikenshtein et al., 1977)

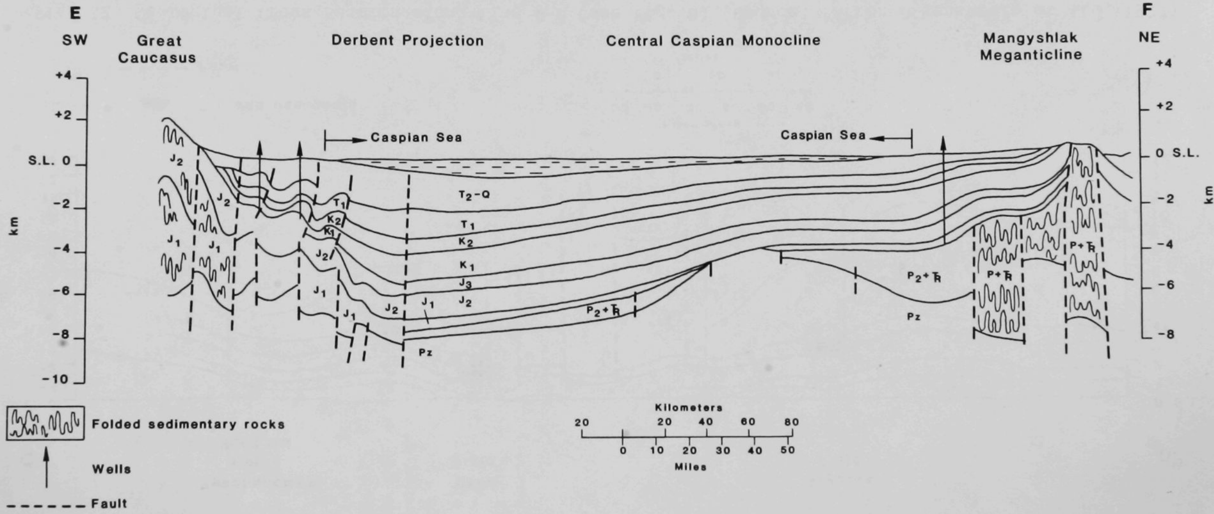

Fig. 13 Geological Cross Section along Line E-F (see Fig. 8) (Source: After Geodekyan et al., 1979)

pre-Cambrian platform. The large North Buzachi uplift occurs in the most western part of the North Ustyurt basin, its southern boundary dilineated by a deep fault that separates the uplift from the South Buzachi trough. Upper Cretaceous rocks are exposed in the core of the uplift, and Middle Jurassic strata occur at a depth of less than 1000 m.

Knowledge of the deep structure in the basin is uneven at best. Although hundreds (even thousands) of wells penetrate the sedimentary cover in producing regions, the structure of the deep depressions is almost completely unknown, particularly beneath the sea. Geophysical data are equally limited, particularly where explosive seismic investigations have been prohibited since the 1960s. (Such prohibition has been justified by the unique fishing resources of the Caspian Sea.) Seismic survey techniques that use nonexplosive energy sources are far behind those used in the West and were initiated only a few years ago.

2.5 STRUCTURAL DEVELOPMENT OF THE PLATFORM COVER*

The structural development of the Middle Caspian Basin was dominated by the gradual subsidence of formations containing organic matter. Different rates of subsidence resulted in generation of oil and gas at different times in different areas of the basin. Paleostructural reconstructions permit interpretations as to the changing foci of oil generation through time and allow relating these foci to regional structures. Such relationships are used to predict the main directions of oil migration as discussed in Secs. 4 and 5.

Tectonic development of the Middle Caspian Basin can be understood by reference to Figs. 14, 15, and 16, which are paleostructural maps on the top of the Middle Jurassic at three important time stages in the geological history of the region. Present-day structures of the Middle Jurassic (see Fig. 9) are a product of still older stages of tectonic development. Rather than giving a detailed description of the origin of each tectonic structure, the major features of the process are described.

Initially, the region developed as a giant, southwesterly dipping monocline that merged with a miogeosyncline occupying the present marginal ridges of the Great Caucasus Mountains (see Fig. 14). The Mesozoic Cis-Dagestan downwarp occupied most of the central Caspian Sea and was separated from the geosynclinal trough by the large Dagestan swell. Even in this early stage, all of the main platform structures were in evidence (Maslyaev, 1979).

The foregoing structural features continued into the next stage of geological development in the Eocene (see Fig. 15). Tectonic units of the northern and eastern parts of the region developed slowly, whereas elements close to the geosyncline underwent more intense subsidence. Although amplitudes of the deepest depressions reached more than 4000 m and the main subsidence took place during late Paleocene-Eocene time, thicknesses of the sedimentary rocks of this age do not exceed 100 m (except for the Stavropol arch). Most of the Cis-Caucasus was covered by a sea with depths of up to 1000 m (Berlin et al., 1978b).

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*Includes the sedimentary cover of the foredeep.

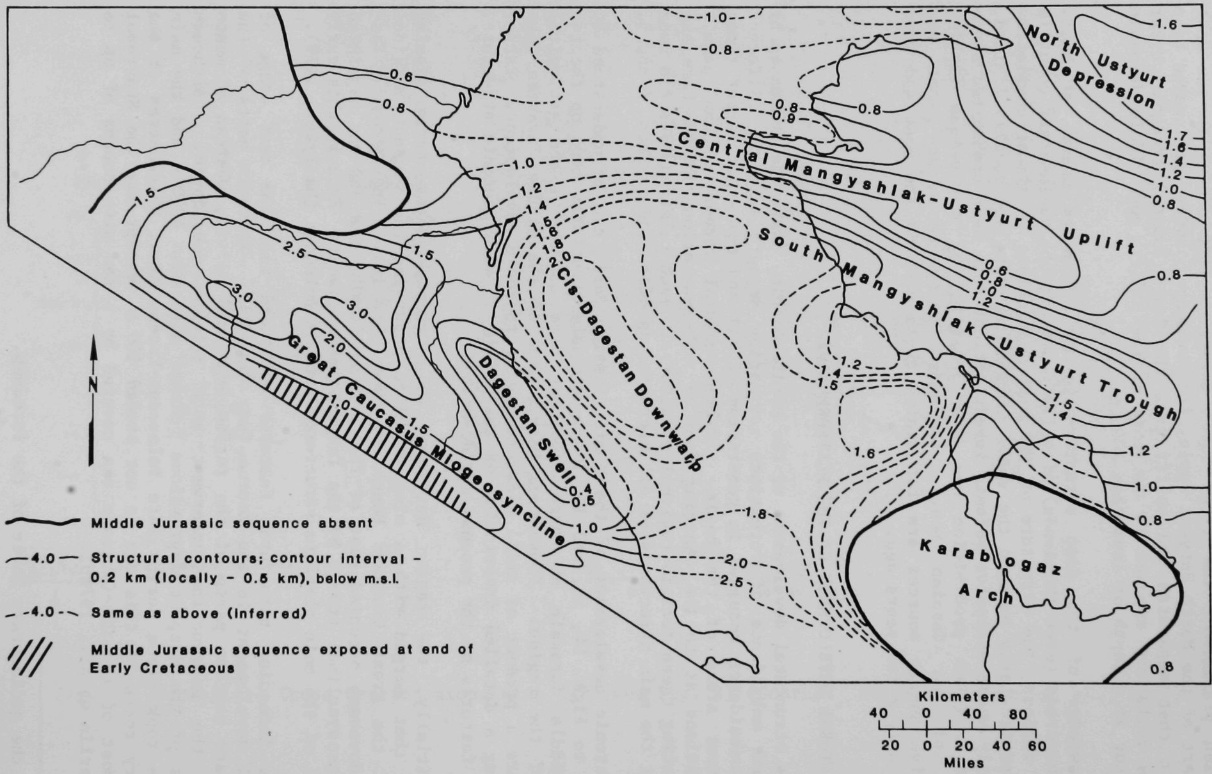


Fig. 14 Paleostructural Map of the Top of the Middle Jurassic, End of Early Cretaceous Time (Source: After Berlin et al., 1978a)

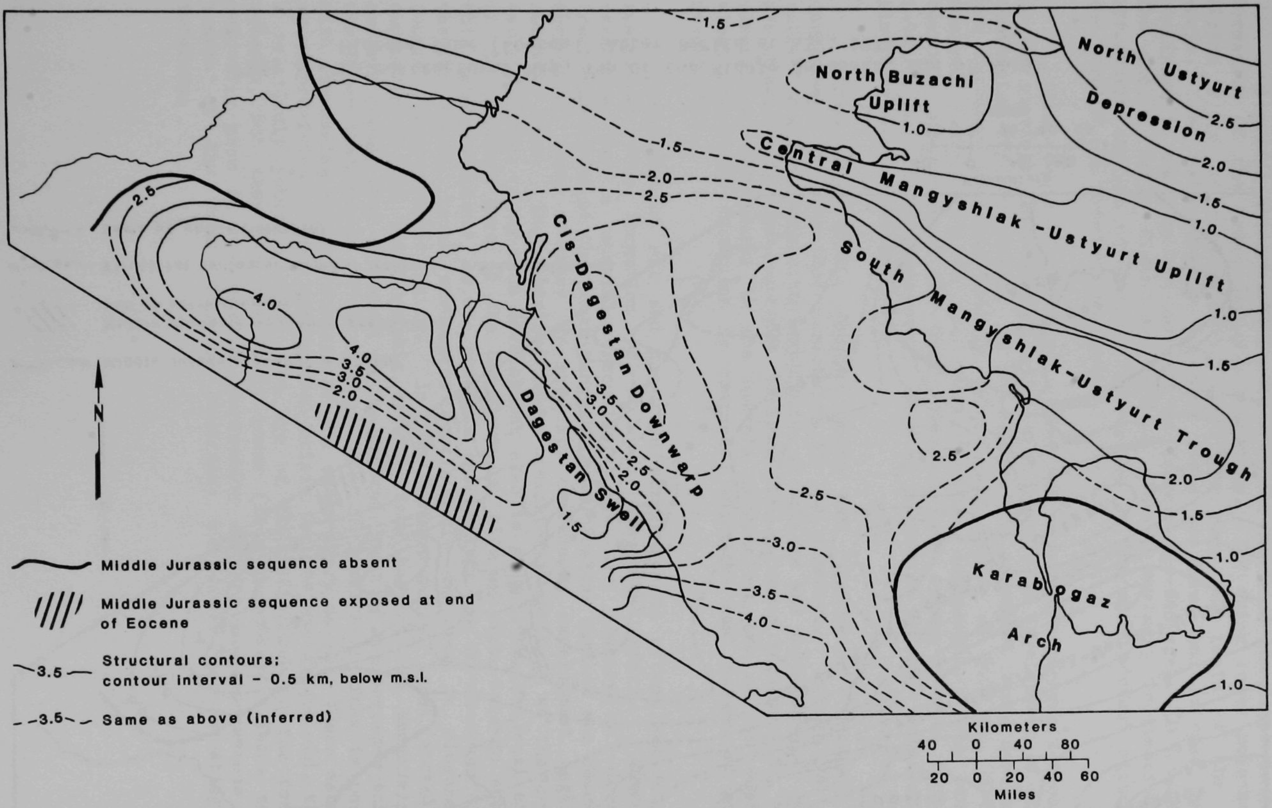


Fig. 15 Paleostructural Map of the Top of the Middle Jurassic, End of Eocene Time (Source: After Berlin et al., 1978a)

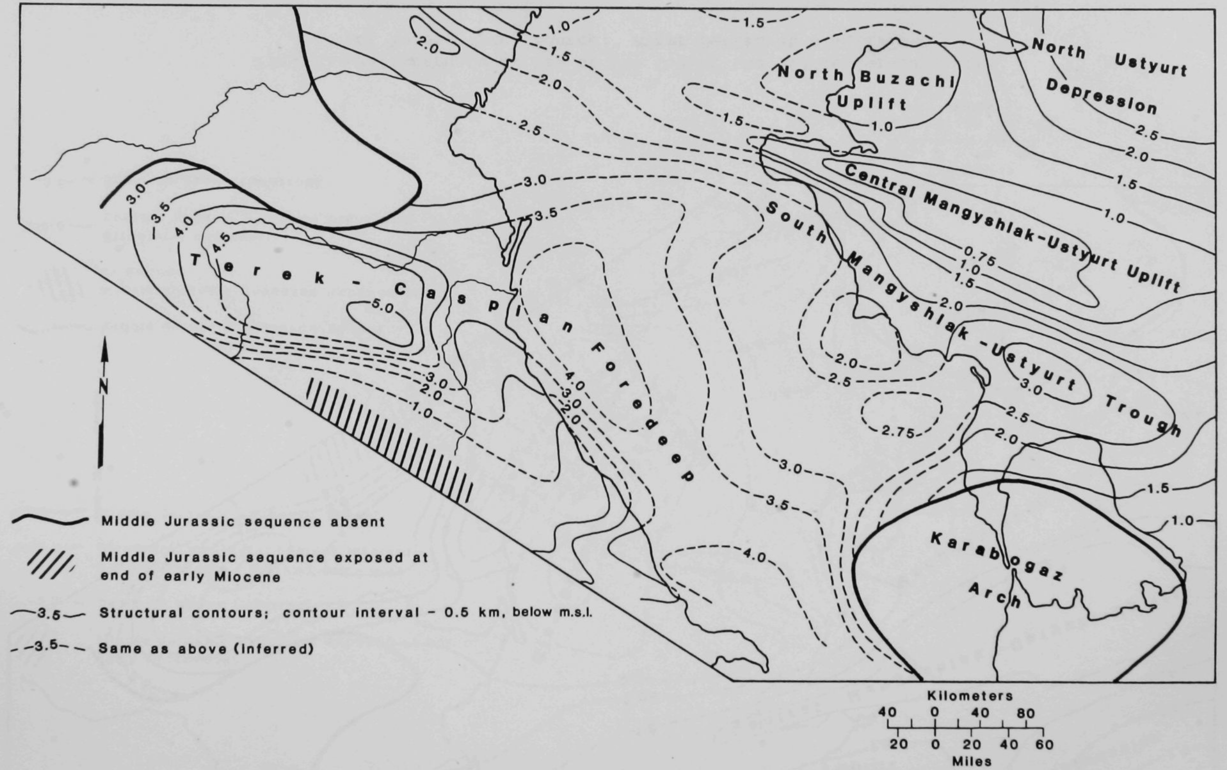


Fig. 16 Paleostructural Map, Top of the Middle Jurassic, End of Early Miocene Time (Source: After Berlin et al., 1978a)

Oligocene through middle Miocene time produced the first stage in the formation of the Great Caucasus Mountains. The thick lower molasse of the Alpine cycle of tectogenesis filled the deep sea basin of the previous stage. The Terek-Caspian foredeep began to form, and intense subsidence continued in the platform part of the Eastern Cis-Caucasus. In contrast with the end of Early Cretaceous time, a general westerly inclination of the structural surface developed. Expression of the more ancient structures in the area of the foredeep decreased.

After early Miocene time, important structural reorganizations ceased in the platform parts of the basin, with only local development of structures continuing (Krylov, 1971). In the geosyncline, however, rapid development of the foredeep produced molasse deposits in excess of 3000 m. Thicknesses reached 7000-8000 m in the North Apsheron depression. The present-day tectonic structure of the Great Caucasus fold system results from intense folding and block movements. Gradual migration of the foredeep to the platform edge is evident.

Thus, the Middle Caspian Basin has experienced continued gradual development of inherited structures in the platform. Present-day features reflect regular, increasing amplitudes of uplifts and depressions. Amplitudes are greatest in the lowermost horizons and decrease regularly in an upward direction. Structures in the basin's geosyncline are of the superimposed kind, and their formation is connected with the last stages of geological development.

Formation of oil and gas trap structures is often, but not always, associated with formation of regional structural units. Almost every structure has a specific peculiarity in its history of development. Brachyanticlines of the South Mangyshlak and Buzachi regions are characterized throughout their history by gradual, continuous development beginning in Jurassic time. They obtained their present-day outlines at the end of the early Miocene. Long-term development also is postulated for local structures of the platform part of the Cis-Caucasus, although some data do not support this interpretation. As one proceeds eastward in the Cis-Caucasus toward the Caspian shore, local structures continuously decrease in closure in the younger stratigraphic units. In the western areas, local anticlines are expressed at all stratigraphic levels (from basement to Neogene); in the eastern areas, they disappear in the Cenozoic part of the sequence and even in the Upper Cretaceous. This disappearance of local anticlines is concomitant with increasing total thickness of the sedimentary cover. These data suggest an upthrust-fault-block (stamplike) origin for the anticlines and, therefore, a relatively youthful age. The age of the anticlines in the foredeep is unknown, but they are presumably young (late Cenozoic). These structures evidently grew in response to compression and are contemporaneous with the growth of the Great Caucasus Mountains and their overthrusting on the foredeep.

3 PALEOGEOGRAPHY, FACIES DISTRIBUTION, AND CONDITIONS OF ACCUMULATION OF ORGANIC MATTER IN THE MAJOR PETROLEUM SOURCE ROCKS

3.1 PERMIAN-TRIASSIC

The Permian-Triassic sequence that forms the intermediate complex is known less well than the overlying sedimentary rocks of the platform cover; drilling data began to appear only during the last 10-15 yr. Even today, many areas of the Middle Caspian Basin have not been drilled. Due to diagenetic alteration the condition of fossils is usually rather poor, and correlation of formations between different regions is often uncertain. This uncertainty is aggravated by insufficient elaboration of the Triassic stratigraphy for different faunal groups. This lack of understanding hampers paleogeographic reconstructions. It is relatively easy and certainly understandable, however, to consider the Permian-Triassic sequence in terms of large areal units. Consequently, for those areas in which the Permian-Triassic sequence is of the same kind, Letavin (1978) proposed the name "taphrogenic formational provinces." Typical sections of the Permian-Triassic sequence in the Middle Caspian Basin are shown in Fig. 17.

In the Eastern Cis-Caucasus, the Permian-Triassic rocks have been studied more extensively than those of other parts of the basin, although there are no wells that penetrate all of their subdivisions. The sequence begins here with the Kuman, a molasselike formation of coarse-grained, arkosic red beds that nonconformably overlie basement rocks. The lower part of the formation usually consists of conglomerates and gritstones that decrease upward in grain size to sandstones and siltstones. In the upper part of the formation, red beds change to variegated and gray, often calcareous rocks with interbeds of argillites. Although the age of the formation is usually considered to be late Permian, this age cannot be verified because of the poor pelecypod fauna. One absolute age determination gave a figure of 230-255 x 10^6 yr, which corresponds to the late Permian (Yudin et al., 1974), but other assessments range from early Permian (Stasenkov et al., 1977b) to Olenek Age (early Triassic) (Lozovskiy et al., 1976). The penetrated thickness of the formation exceeds 700 m. Deposition of the Kuman formation took place in a system of lakes and rivers and, in the upper part of the formation, in a brackish water basin with an oxidizing environment. The rocks are characterized by a low content of organic carbon (usually 0.20-0.25%) and bitumen (not more than 0.01%). Reservoir properties of the rocks are rather poor as a rule, with an average effective porosity of 6.4% and low permeability.

The Neftekumsk formation, mainly a carbonate unit of two facies, usually overlies the red beds with a slight disconformity. The first facies consists of reef-type, light-colored, often dolomitized limestones; the second is made up of dark-gray, thinly laminated, platy, and sometimes argillaceous limestones. A forereef facies rich in detritus occurs between them (Artsyshevich et al., 1978). The age of the Neftekumsk formation has not been determined with any certainty but, as a rule, it is considered to be part of the Ind Stage of the Lower Triassic. At least the upper part of the reefs is of the Olenek Stage, because Olenek ceratites were found in the forereef facies at the base of the Molodezhninsk formation. The main algal barrier reef of the Neftekumsk formation is 3-6 km wide and 80 km long, and is connected with the southern border of the East Manych taphrogen

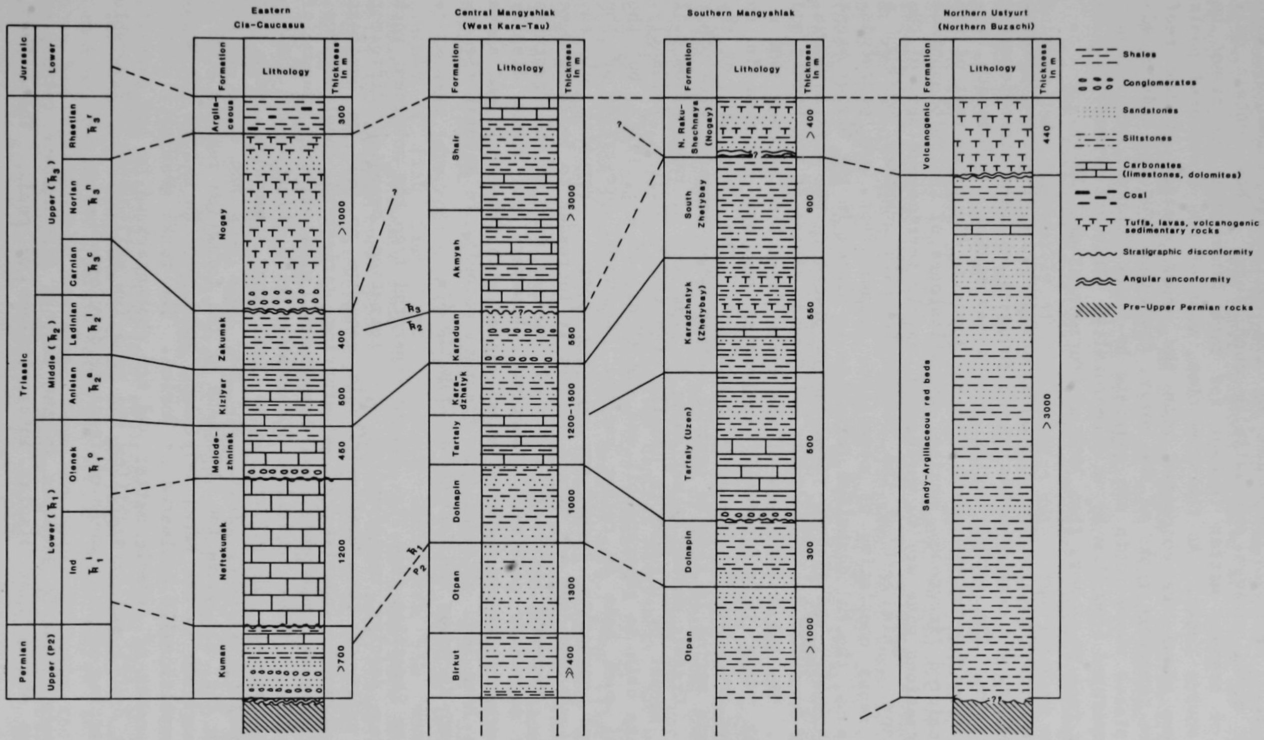


Fig. 17 Geological Sequences of Permian-Triassic Rocks (Sources: Compiled from Letavin, 1978, and Florenskiy, 1976)

(Gorkushin et al., 1975). Limestones of the Neftekumsk formation were deposited under normal oxygen and salinity conditions. They contain only small amounts of organic matter (except for rare interbeds) and cannot be considered as source rocks. At the same time, most of the discovered pools and oil and gas shows are connected with the upper section of the reef limestones where reservoir rocks of the vuggy, fractured type are widespread, especially in places where reefs are overlain by Upper Triassic and Jurassic beds and are separated from them by an unconformity. Fracture permeability in the zone varies from 24 to more than 3000 md (Fursova et al., 1974).

The clastic-carbonate series of the Molodezhninsk, Kizlyar, and Zakumsk formations (see Fig. 17) occurs higher in the sequence and lies disconformably on subjacent reefs. The series begins with a variegated conglomerate bed. The percentage of carbonates decreases from the lower to the upper part of the series. Gray-colored limestones, shales, and siltstones of the Molodezhninsk and Kizlyar formations give way to variegated, mainly terrigenous beds of the Zakumsk formation. This part of the Permian-Triassic sequence exhibits a well-preserved fauna consisting of ceratites, foraminifera, and ostracods. Based on the fauna, the Molodezhninsk formation is placed in the Olenek Stage of the Lower Triassic, the Kizlyar formation is placed in the Anisian Stage, and the Zakumsk formation in the Ladinian and Carnian stages of the Middle and Upper Triassic. The total thickness of the three formations reaches 1400 m. Deposition took place in a gradually regressing sea and finished in an embayment, under only partly subaqueous conditions. The lower half of the clastic-carbonate series is rich in organic matter, when compared with other Triassic rocks. Organic carbon is variable; in some beds it ranges from 0.4% to 2.2%. The amount of bitumen is usually high (up to 0.3%). Evidently, these rocks were able to generate oil and gas (Yudin et al., 1974), but the distribution of such beds is rather uneven. Reservoir properties of the terrigenous and carbonate rocks are usually poor. Porosity of the argillaceous limestones does not exceed 5%, but it increases to 5-12% in some sandstone beds. Permeability is only 1-3 md, because most of the fractures are filled by secondary calcite. Sometimes, however, the rocks display porosity and permeability values usually associated with fractures, and shows of oil and gas have been obtained from fracture porosity in several fields, such as the North-Kochubey and East-Sukhokumsk fields.

The Nogay formation (see Fig. 17) is separated from the subjacent rock sequence by an angular unconformity; the formation overlies different stratigraphic units of the Permian-Triassic sequence as well as basement rocks. The formation consists of alternating variegated conglomerates, sandstones, siltstones, mudstones, and limestones, with varying amounts of volcanic materials. These rocks are interbedded with thick layers (up to several hundred meters) of silicic lavas and, more commonly, tuffs and ignimbrites (Burshtar et al., 1973). The most lava beds are found in the Nogay zone (see Fig. 6), where the thickness of the formation reaches 1000 m. Based on its position in the Permian-Triassic sequence, the age of the Nogay formation is conditionally evaluated as Norian. The rocks generally contain only a small amount of organic matter and are characterized by low porosity (not more than 8-10%) and permeability (up to a few millidarcy). Favorable reservoir properties occur in zones of fracture development.

The Permian-Triassic sequence in the Eastern Cis-Caucasus terminates with lacustrine shales that display intercalations of coal. These beds, presumably of Rhaetian-Liassic age, occur mainly in depressions of pre-Jurassic relief and are more closely related to those of the superjacent Mesozoic sequence.

An extremely thick (up to 9000 m) sequence of Permian-Triassic rocks is present in central Mangyshlak. It is well studied because most of it is exposed in the western Kara-Tau Mountains.

The variegated, clayey Birkut and sandy Otpan formations represent molasse beds, presumably of late Permian age. The Triassic sequence begins with deltaic red beds of the Dolnapin formation (see Fig. 17). Overlying this formation are shallow marine limestones and shales of the Tartaly formation and shales and sandstones of the Karadzhatyk formation of the Olenek Stage. The Middle Triassic is represented by the Karaduan formation, which consists of coarse-grained red beds. Unique for central Mangyshlak is a thick marine sequence of late Triassic age that is absent in adjacent areas. It consists of the mainly carbonate Akmysh and terrigenous Shair formations. These beds were deposited in a narrow trough and, together with the underlying formations, were uplifted and folded at the end of Triassic time. All the Triassic rocks in central Mangyshlak are strongly changed epigenetically and cannot be considered potential reservoir rocks.

In the South Mangyshlak trough, oil production has been obtained from Triassic rocks, and these rocks are a target for further exploration. The oldest rocks penetrated by wells are part of a sequence that consists of dark-colored, polymictic sandstones and black shales. They are correlated conditionally with the Otpan formation of central Mangyshlak, but some geologists believe they are of Carboniferous age (Letavin, 1978). These rocks are greatly changed epigenetically; their density is 2.7 g/cm^3 (Florenskiy et al., 1976), and their porosity does not exceed 3% (Florenskiy et al., 1974). Overlying these rocks are brown shales and medium-grained sandstones, which are poor in organic matter and lithologically close to the Dolnapin formation.

The marine Triassic sequence begins with Olenek beds and includes Middle Triassic rocks. These are dark-colored shales, limestones, and siltstones interbedded with sandstones and, rarely, silicic tuffs. The rocks contain a rich fauna and correlate well with the western Kara-Tau formations. Carbonate rocks predominate in the lower part of the sequence, while terrigenous rocks predominate in the upper part. Both the shales and the limestones are characterized by a high content of dispersed organic matter (up to 9.8%), which is mainly of the sapropelic type. The organic matter is rich in syngenetic bitumens (Letavin, 1978). The best petroleum reservoirs in the Triassic are also found in this part of the sequence (Yedrenkin and Demidov, 1977). Reservoir rocks typically are beds of oolitic, caprolitic, and detrital carbonates with a porosity of up to 21.4% and a permeability of up to 14.5 md. Reservoir properties are significantly improved in zones of extensive fracturing (Yedrenkin and Piyp, 1976).

Upper Triassic rocks are penetrated by wells near Cape Rakushechnyy (see Fig. 2). They are similar to the Nogay formation of the Eastern Cis-Caucasus, but do not contain lavas and include fewer tuffs. At the same time, they are considerably different from the Upper Triassic rocks of central Mangyshlak. Presumably, they are younger and formed after the deposition of the marine clastics and cabonates of central Mangyshlak. These rocks are combined in the North Rakushechnaya formation and supposedly occur in the axial zone of the South Mangyshlak trough (Yuferov et al., 1977). Upper Triassic reservoirs are not as good as those in subjacent beds. Average effective porosity in the sandstones and siltstones is 7.0%, with a range of 2.2-12.8%. Effective porosity for all rocks of the formation decreases to 6.3% (Yedrenkin and Piyp, 1977).

In the North Ustyurt basin, the most complete Permian-Triassic sequence (3000 m) is penetrated on the northern slope of the North Buzachi uplift. Most of the sequence is made up of alternating red and brown sandstones, siltstones, shales, and tuff argillites, with rare interbeds of limestones. Coarse-grained rocks predominate in the upper part of the sequence while the most widespread rocks in the lower part are shales. The age of the red beds is unknown, but they are thought to belong to the Olenek Stage (Golov et al., 1979) or to correspond to all stages of the Early and Middle Triassic (Letavin, 1978). Average effective porosity of the sandstones and siltstones is 3.2-6.5%, and their permeability is extremely low. Geochemical investigations indicate that these rocks are not capable of generating oil and gas (Letavin, 1978). Nonmarine sedimentary and volcanic rocks occur above the red beds. The areal extent of these rocks is unknown. They may only be associated with local faults. They are absent in the southern part of the Buzachi peninsula. There the Upper Triassic consists of deformed marine shales with a thickness of up to 425 m.

Thus, the lower part of the Permian-Triassic section in the Middle Caspian Basin consists of terrestrial molasses that grade upward into marine beds. However, these facies are not everywhere contemporaneous. There is evidence for a nonmarine environment through all the stages only in northern Ustyurt. The marine formations were adequate source rocks, and they possess the best reservoir properties in the sequence. Significant tectonic movements occurred before the time of Nogay sedimentation. Sedimentary and volcanic rocks of this age overlie various formations and are separated from them by an angular unconformity. During this time, the thick sequence of marine rocks presumably was formed in the narrow Central Mangyshlak taphrogen. The time of inversion and folding in this taphrogen may be correlated with the deposition of volcanic rocks. A large interruption in sedimentation, accompanied by erosion and reorganization of the Triassic structural pattern, took place at the end of the Triassic or in Early Liassic time. Jurassic and younger sedimentary rocks overlie Triassic formations with an angular unconformity. During this time, lacustrine sediments were deposited locally in structural and erosional lows.

3.2 EARLY-MIDDLE JURASSIC

Lower and Middle Jurassic sedimentary rocks overlie the subjacent sequence with angular unconformity. They cover a vast area but are absent on the Stavropol and Karabogaz arches and on the southern portion of the Prikumsk swell (see Fig. 18). A transgressing sea gradually spread over the area at this time, and deposition took place under warm and humid climatic conditions.

During Early Jurassic (Liassic) time, the sea existed only in the geosynclinal trough, where more than 5000 m of mainly clayey sediments were deposited. Sediment thicknesses decreased sharply along the borders of the

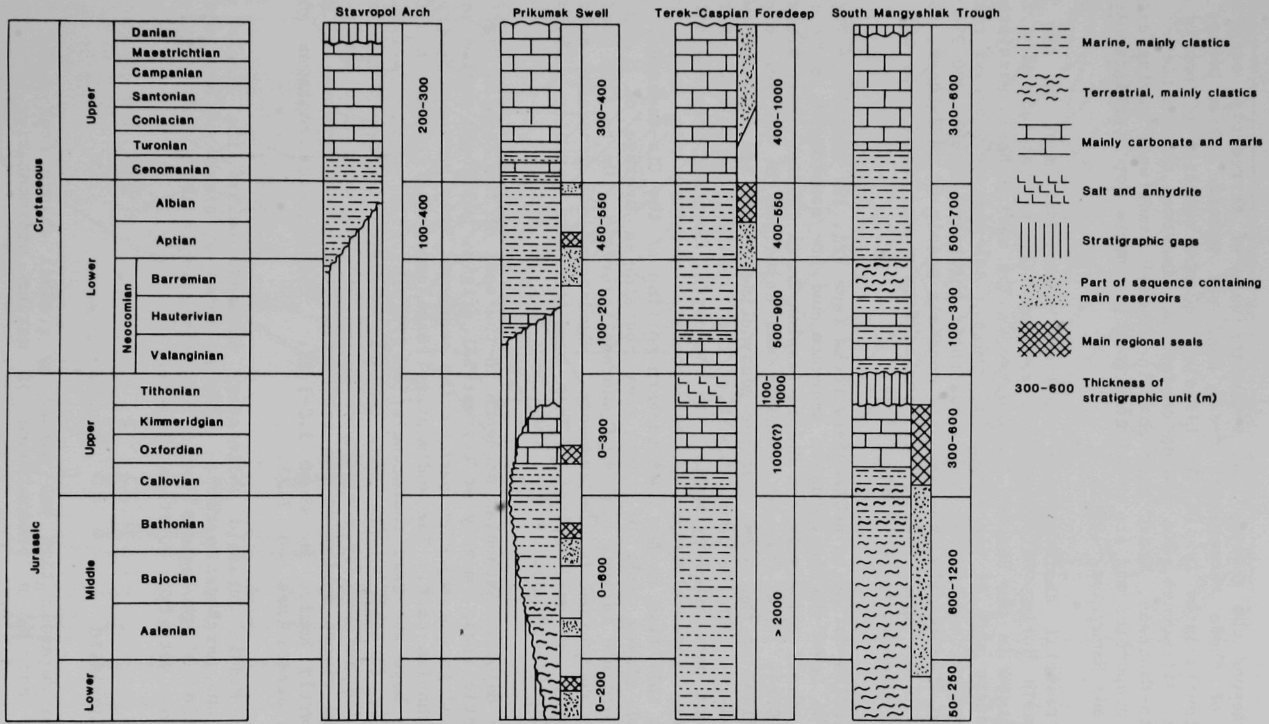


Fig. 18 Geological Sequences of Jurassic and Cretaceous Rocks

trough. Beyond the geosyncline, sediments were of terrestrial origin. The thickness of these terrestrial rocks does not exceed 200 m today; it is usually significantly less. The Liassic sequence consists of poorly sorted sandstones, siltstones, and shales containing dispersed coal matter. In the Eastern Cis-Caucasus, basal beds contain channel sandstones having excellent reservoir properties and are considered good prospects for stratigraphic traps (Burshtar and Manuylova, 1978).

Terrestrial sedimentation continued throughout most of the Middle Caspian Basin during Aalenian time, although the sea occasionally flooded platform areas in the Eastern Cis-Caucasus. The marine basin persisted only in the eastern part of the Karpinskiy ridge. Aalenian sedimentary rocks are more widespread than Liassic rocks, and their thickness reaches 200-250 m. In the Eastern Cis-Caucasus, the sequence consists mainly of sandstones, followed by shales in its upper part. These shales form a seal that traps oil in the underlying Aalenian rocks (Yudin, 1977).

Bajocian-Bathonian sedimentary rocks (see Fig. 19) constitute the major part of the Lower-Middle Jurassic sequence and are considered to be a major generator of oil and gas in the Middle Caspian Basin (Yudin, 1977; Vlodarskaya et al., 1978). The thickest sequence was deposited in the sea along the southern flank of the Great Caucasus geosyncline. This sea expanded over the platform slope. In the deepest part of the foredeep, the Bajocian-Bathonian beds are not penetrated by wells. To the north, they are composed mainly of shales with intercalations of sandstones. Another sea basin existed throughout this time in the northeastern portion of the Cis-Caucasus. Sandy, silty, and clayey beds of this area contain an average of 1.0-1.2% of dispersed organic carbon, mostly of sapropelic origin. Up to five productive strata are recognized in the sequence. Sandstones are generally quartzose, fine-grained, and well sorted. They have moderate porosity (12-17%) and permeability (20-60 md).

The Bajocian-Bathonian sequence to the east of the Caspian Sea is made up of clastic rocks, mostly of terrestrial origin. Although marine beds are seldom found in the Bajocian part of the sequence, they become more prevalent in the Bathonian part. The sedimentary rocks under the floor of the Caspian Sea likely have the same characteristics (Pilyak, 1978). An alluvial plain, occasionally flooded by the sea, probably divided the two persistent sea basins. The sedimentary environment was a reducing one, with large lakes, swamps, and rivers making up the landscape. The average content of organic carbon (partly humic) is about 1.0-1.3%. The sequence contains numerous productive strata (see Sec. 7.2).

The Middle Jurassic sedimentary sequence onlaps the flanks of the Stavropol and Karabogaz arches. Although zones of pinch-out have attracted the attention of geologists for a long time, exploration for stratigraphic traps has not yet given positive results.

3.3 LATE JURASSIC

Late Jurassic time was marked by gradual change from humid to arid conditions and by a predominance of marine sedimentation (see Fig. 20).

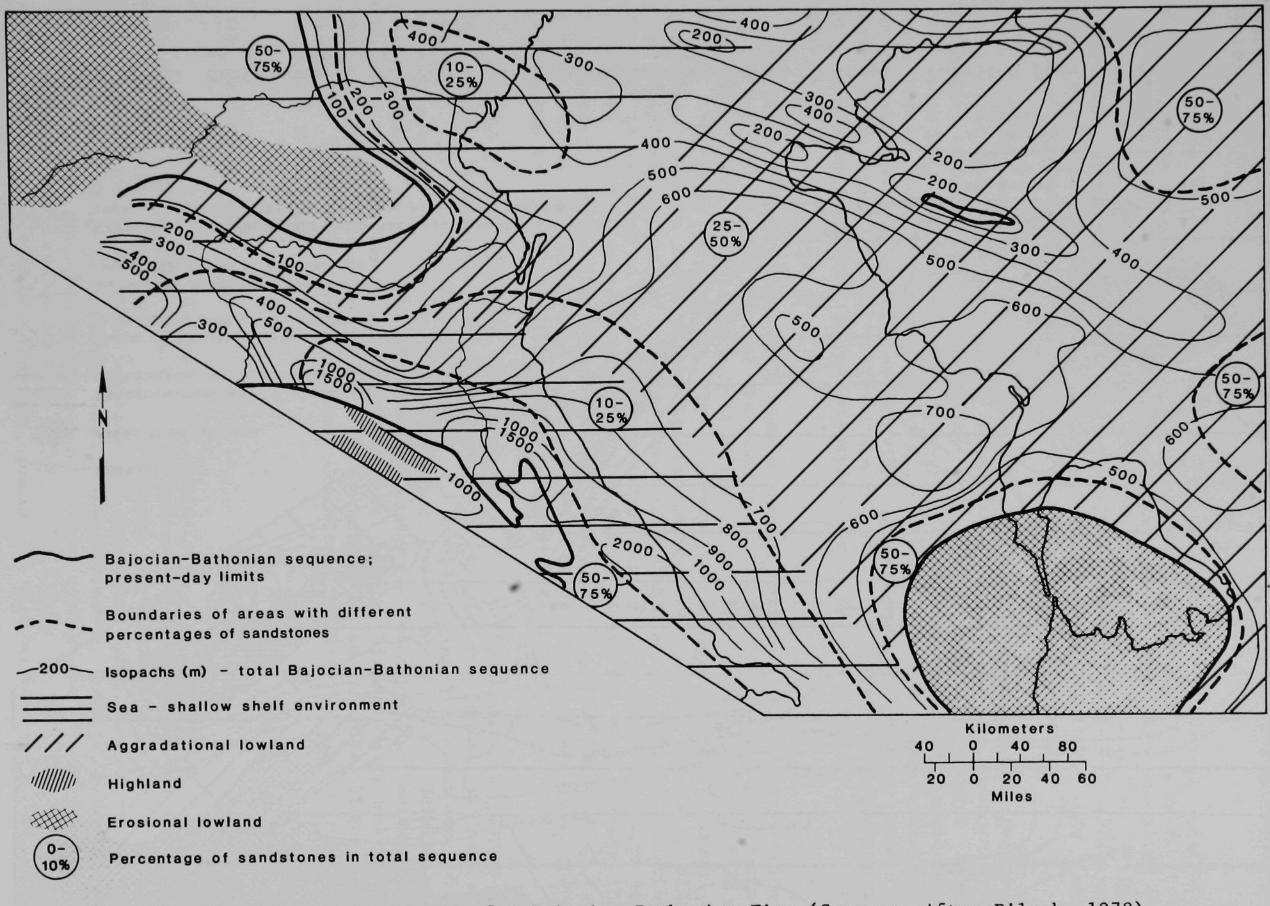


Fig. 19 Paleogeographic Map for Bajocian-Bathonian Time (Source: After Pilyak, 1978)

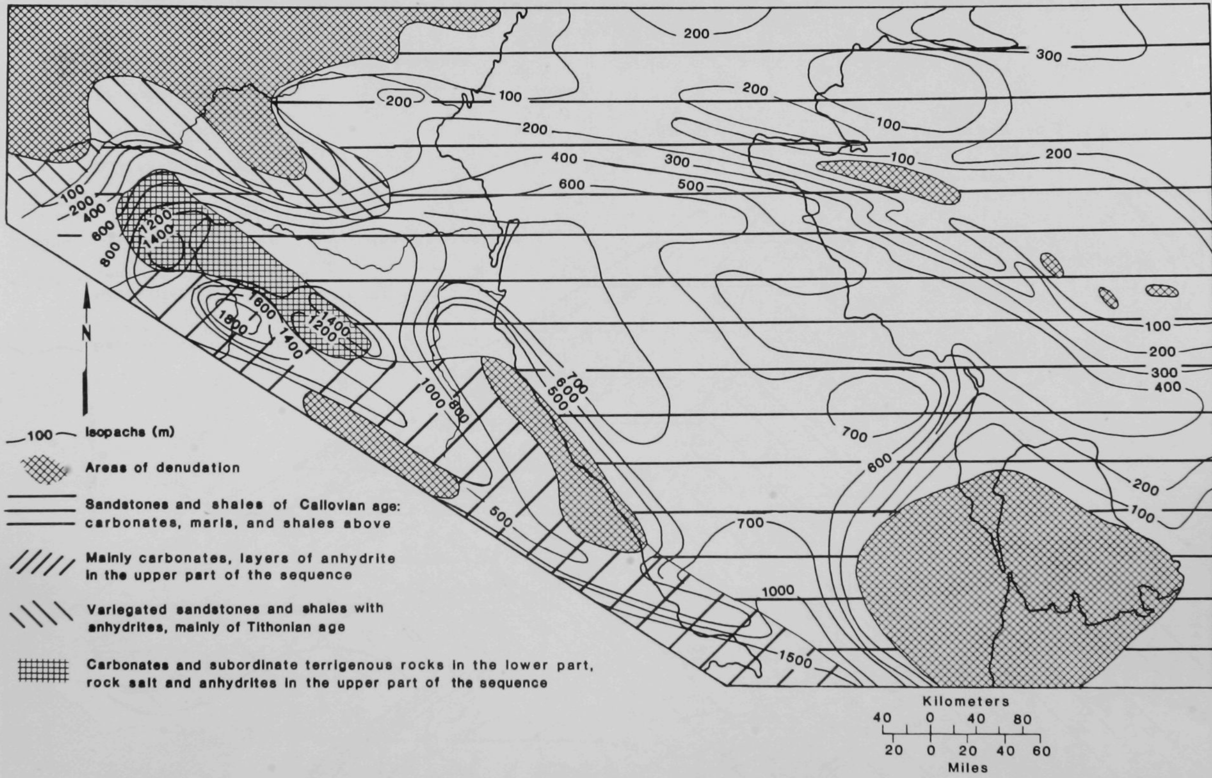


Fig. 20 Facies Map of the Upper Jurassic Sedimentary Rocks (Sources: Compiled from Berlin et al., 1978a; Polster et al., 1972; and Derevyagin and Sedletskiy, 1977)

Maximum transgression occurred in Oxfordian time, after which the sea began to retreat.

In the beginning of Callovian time, deposition of clastic sediments still occurred over most of the basin. Nonmarine sedimentation predominated in the region to the east of the Caspian Sea. Channel sands were deposited in the well-developed river system (Yuferov et al., 1978). The marine environment began here in middle Callovian time. In the Eastern Cis-Caucasus, marine clastic sediments were deposited throughout Callovian time. Only along the Great Caucasus geosyncline did carbonate sediments predominate.

During the Oxfordian and Kimmeridgian stages, a marine transgression covered the Middle Caspian Basin, except for the areas of the Stavropol and Karabogaz arches. A large uplift also existed in the Derbent area. Deposition of carbonaceous and clayey-carbonaceous sediments predominated everywhere. These sediments now form one of the most important impermeable rock complexes. A gradual shallowing and retreat of the sea began in Kimmeridgian time. In the southwestern portion of the Eastern Cis-Caucasus, beds of gypsum and anhydrite are widespread among the carbonate rocks of this age.

The Tithonian Stage was a time of rapid subsidence of the geosynclinal trough and the adjacent part of the platform. The deep sea of the geosyncline was divided from the platform by a chain of barrier reefs more than 1000 m high. They are exposed in the northern ranges of the Great Caucasus Mountains. To the north of the reef chain, several hundred meters of salt were deposited in a saline basin in the Terek-Sunzha region. The salt-bearing sequence is bordered on the north by a narrow zone of terrestrial red beds and variegated clastic rocks with intercalations of anhydrite that overlie the pre-Jurassic sequence (Derevyagin and Sedletskiy, 1977). Over the rest of the region, Tithonian beds are absent, their place in the sequence being represented by a regional disconformity (see Fig. 18).

Only a few productive stata are found in the Upper Jurassic sequence. They occur mainly in the lowermost part of the Callovian sedimentary section. In the Mangyshlak region, oil pools are mostly associated with channel sandstones characterized by good reservoir properties. Several oil and gas pools in Callovian sedimentary rocks are found in the Eastern Cis-Caucasus. In the Terek-Sunzha region, a relatively thin carbonate bed at the top of the Upper Jurassic sequence is productive in two fields. These pools occur in fractured limestones and dolomites exhibiting highly variable reservoir properties.

3.4 NEOCOMIAN

Neocomian time (Valanginian, Hauterivian, and Barremian ages) was characterized by unstable conditions of sedimentation and a gradual change in climate from arid to humid. In the Eastern Cis-Caucasus, the thick (up to 800 m) Valanginian carbonate sequence was deposited along the borders of the geosyncline. These sedimentary rocks pinch out rather quickly to the north. Hauterivian, and especially Barremian, marine terrigenous rocks are spread considerably wider and pinch out only on the flanks of the Stavropol arch. Their thickness decreases northwards, concurrent with an increase in sandstone content. This is an important oil-producing complex; it contains fractured reservoir rocks in the lower part and clastic reservoir rocks in the upper part. On the Prikumsk swell, up to six productive sandstone strata are distinguished in the Hauterivian and Barremian sequence. Of particular importance is stratum IX at the top of the Barremian. Porosity of the sandstones is 18-20%; permeability varies significantly but usually is 100-300 md.

On the northern portion of the Karabogaz arch, sedimentation began in a marine lagoon environment. In the South Mangyshlak trough, 200-300 m of marine clastic and subordinate carbonate sediments were deposited. In Barremian time, the sea retreated from this region, and terrestrial sandstones and shales lie at the top of the Neocomian sequence.

3.5 APTIAN-ALBIAN

In Aptian-Albian time (see Fig. 21), marine conditions prevailed over almost all of the Middle Caspian Basin. Only in the central portion of the Stavropol arch was land preserved through Aptian time, and this part of the arch was flooded by the sea during the second half of the Albian Age. Terrigenous sedimentation predominated everywhere. The sandstone content is highest on the Prikumsk swell and in the easternmost part of the basin. It decreases gradually toward the Caspian Sea and the area of the present Great Caucasus Mountains, where a relatively deeper sea existed. Decreasing sandstone content on the Stavropol arch is related to the pinch-out of the lowermost part of the sequence, which contains the main sandstone beds. The Aptian-Albian sequence in the Eastern Cis-Caucasus and probably beneath the Caspian Sea is believed to be an important oil-generating horizon. It averages 1-2% sapropelic organic matter and lies at depths favorable for its transformation (Berlin and Ulmishek, 1978a; Geodekyan et al., 1978b). Aptian-Albian sedimentary rocks, together with stratum IX at the top of the Barremian, form the main producing sequence of the Eastern Cis-Caucasus. Most pools are connected with stratum VIII in the lower part of the Aptian sequence. This stratum is overlain by a widespread seal of shales. The average porosity of stratum VIII sandstones is 18-20%; permeability is 100-300 md.

Dispersed organic carbon in the Aptian-Albian sequence to the east of the Caspian Sea usually is 0.5-1.5%. Except for the deepest part of the South Mangyshlak trough, however, these sediments were never buried deeply enough for large-scale oil generation (Geodekyan et al., 1978b).

3.6 LATE CRETACEOUS

Rather uniform marine sedimentation predominated in Late Cretaceous time (see Fig. 22). There was no significant difference in the nature of sedimentation between the platform and the northern part of the geosyncline. However, in the southeastern pericline of the geosyncline, more than 2000 m of carbonaceous-terrigenous flysch were deposited.

At the beginning of this time (Cenomanian), clastic sedimentation in the eastern part of the basin continued without interruption from the Albian Age. Cenomanian sandstones and shales constitute about 30% of this sequence. Deposition of carbonates began in this region during Turonian time

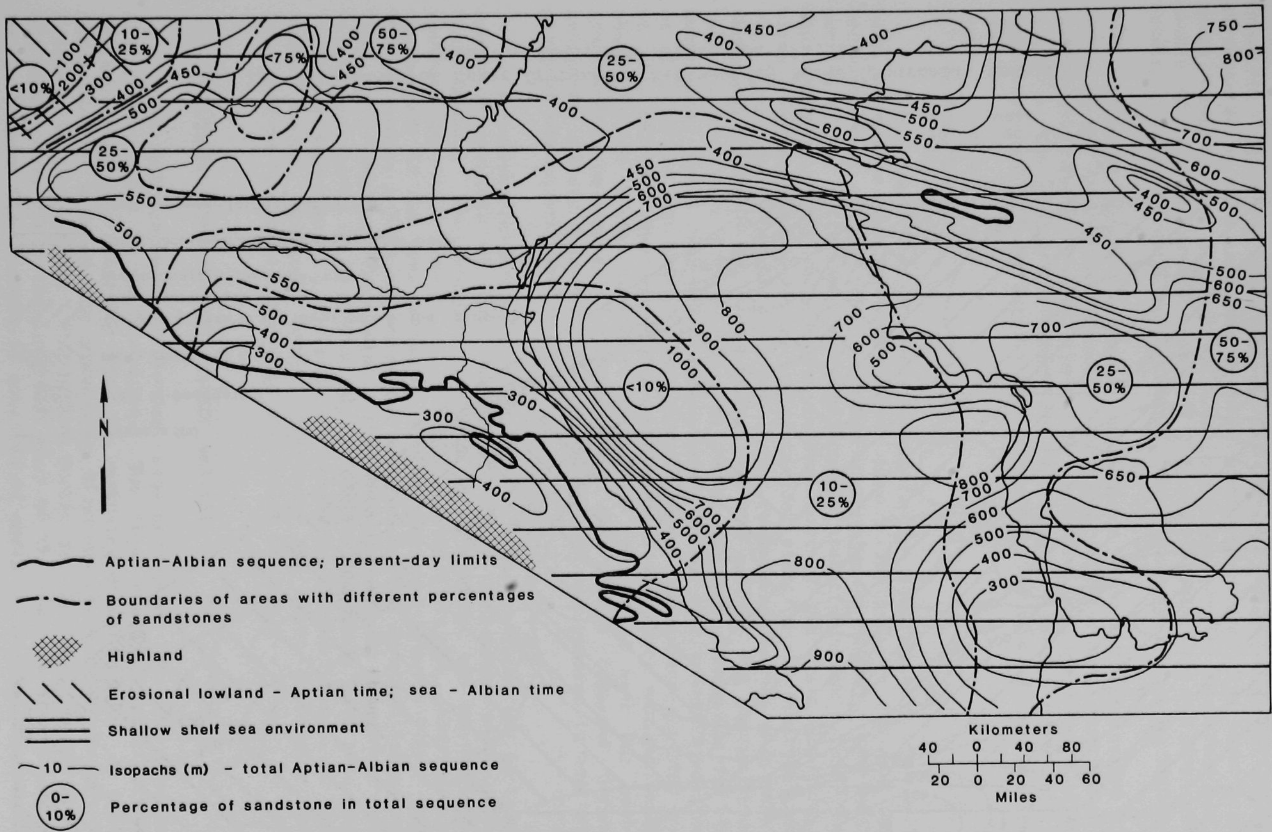


Fig. 21 Paleogeographic Map for Aptian-Albian Time (Source: After Berlin and Ulmishek, 1978a)

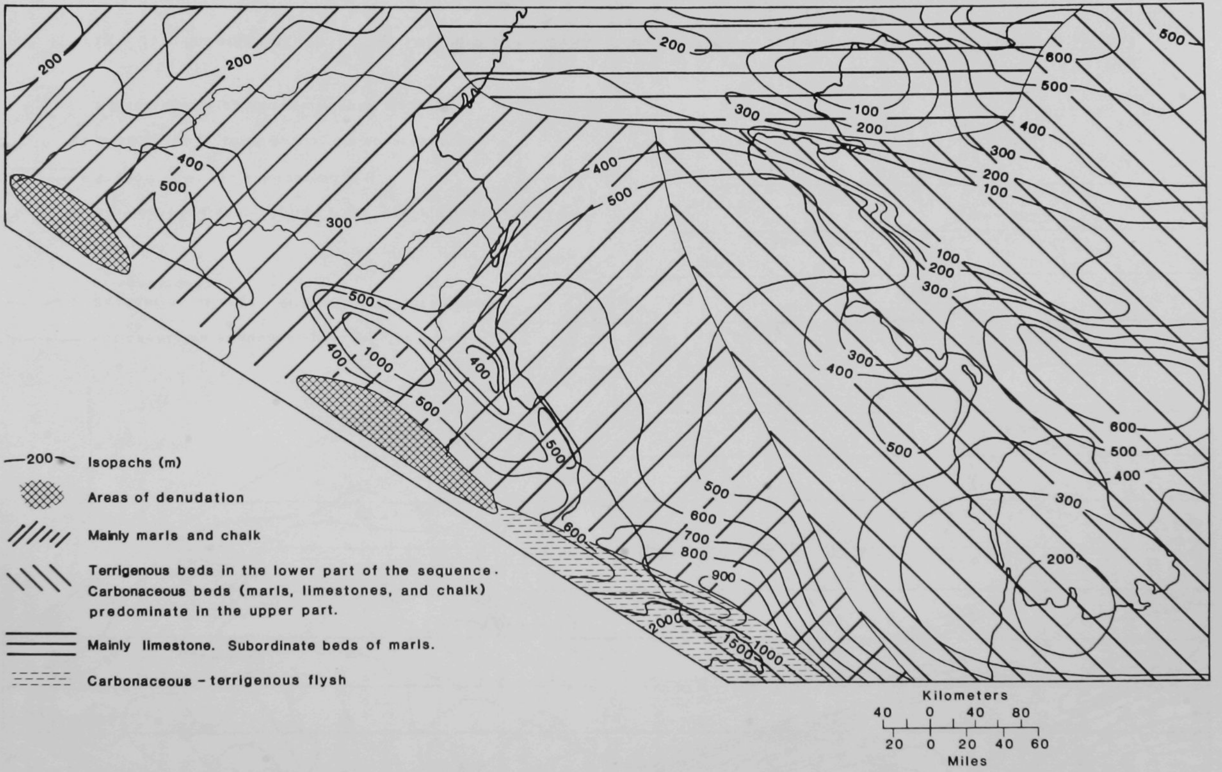


Fig. 22 Facies Map of Upper Cretaceous Sedimentary Rocks (Sources: Compiled from Berlin et al., 1978a, and Polster et al., 1972)

(see Fig. 18). In the Eastern Cis-Caucasus, the Cenomanian sequence is represented by thin carbonate rocks disconformably overlying Lower Cretaceous rocks (Sokratov et al., 1977). Maximum transgression occurred during the middle of Late Cretaceous time. At the end of this time the sea retreated, causing a large break in sedimentation, which corresponds to the Danian Stage.

Although Upper Cretaceous sedimentary rocks are productive in many fields in the Eastern Cis-Caucasus, the major reserves are concentrated in the Terek-Sunzha region. The reservoir properties of oil-bearing limestones depend on the degree of fracturing, which varies widely. Porosity of the limestones is 3-12%; permeability is from about 2-3 md to 200 md and more.

3.7 PALEOCENE-EOCENE

Significant changes in paleogeographic environment occurred between Late Cretaceous and Paleocene-Eocene time. Following a regional break in sedimentation, a new cycle of marine transgression began. The westernmost portion of the basin subsided significantly; relatively small land areas were apparently preserved only in the central part of the Great Caucasus geosyncline. Deposition of clastic sediments took place on the Stavropol arch (see Fig. 23). The thickness of sandy-clayey rocks here reaches more than 800 m. Carbonate sedimentation predominated over the rest of the basin. Sedimentation to the east of the Stavropol arch did not compensate for tectonic subsidence, and a deep-water marine basin formed over a vast area (Geodekyan et al., 1975). The depth of the basin in some places exceeded 1000 m (Berlin et al., 1978b). The sea became shallower to the east; maximum depths were about 200-300 m in the South Mangyshlak trough and near the present-day Krasnovodsk peninsula. Thickness of the mainly deep-sea carbonaceous sediments nowhere exceeded 150 m, although it was greater in the shallower parts of the ancient basin.

A remarkable part of the sequence is the Kuma formation of late Eocene age. It consists of dark, highly bituminous limestones intercalated with black shales. The formation is about 20-30 m thick, and the organic matter content may reach 15-17%. In the Mangyshlak region, the stratigraphic counterpart of the Kuma formation is the so-called Rybnaya (Fish) formation, which contains a high concentration of uranium that is mined intensively. In the North Ustyurt depression, the Paleocene-Eocene sequence is mostly terrigenous rocks up to 300 m thick. Several gas pools have been discovered in Eocene sandstones to the east of the Middle Caspian Basin. In the Terek-Sunzha region, Paleocene-Eocene limestones and Upper Cretaceous carbonates form massive fractured reservoirs containing oil pools.

3.8 OLIGOCENE-EARLY MIOCENE (MAYKOP SERIES)

The Oligocene-lower Miocene sequence (see Fig. 24) represents a distinctive cycle of sedimentation. The first stage of uplift of the Great Caucasus Mountains coincides with the beginning of this cycle. As uplift took place in the area of the previously existing geosynclinal trough, a large foredeep began to form. The Maykop Series is everywhere composed of shales and sandstones. Only the lowermost part of the sequence (the Khadum horizon) in the Eastern Cis-Caucasus is composed of marls a few tens of meters thick

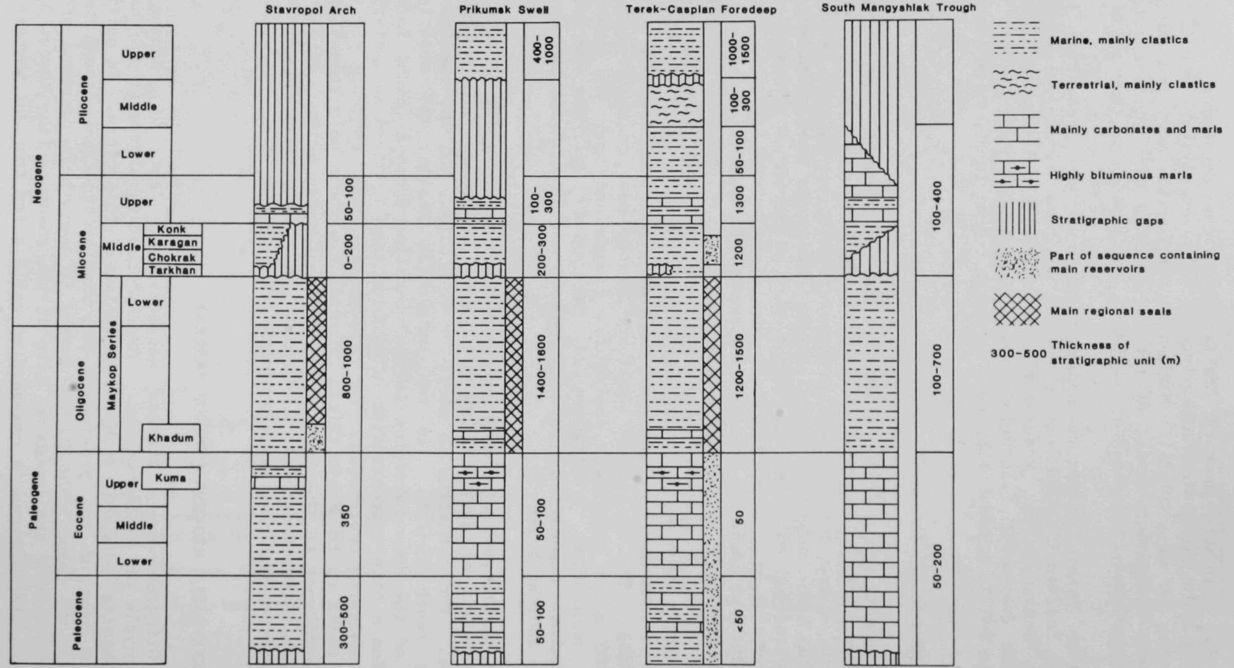


Fig. 23 Geological Sequences of Cenozoic Rocks

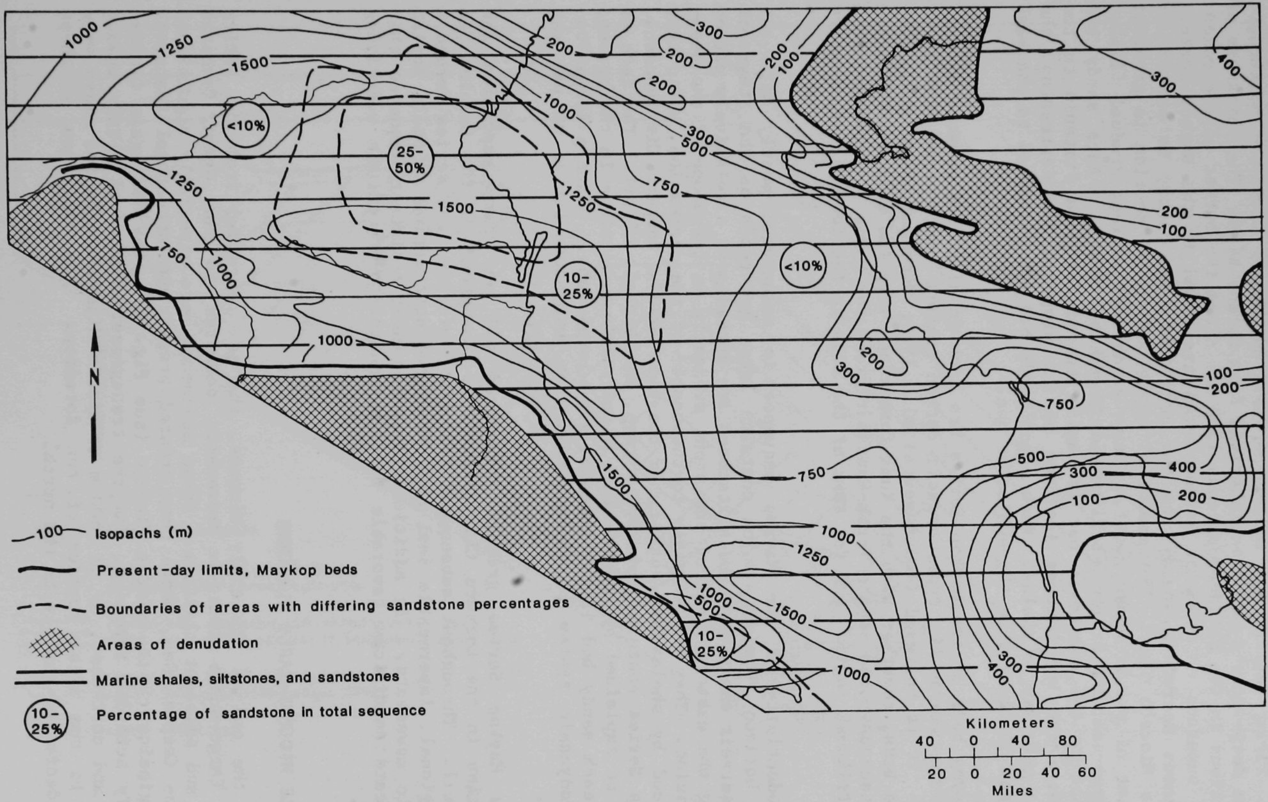


Fig. 24 Facies Map of Oligocene-Lower Miocene (Maykop) Sedimentary Rocks (Source: After Berlin and Ulmishek, 1978b)

(see Fig. 23). Terrigenous sediments, derived mainly from the northeast, filled the deep-water depression inherited from Eocene time. The thickness of the formations in the foredeep exceeds 1500 m. Along the border of the paleo-Caucasus, numerous erratics of Eocene rocks are found in the Maykop Series. Its thickness decreases sharply to the northeast, due partly to erosion in pre-middle Miocene time. The amount of sandstone in the section is greatest to the east of the Prikumsk swell. These sandstones reflect gradual filling of the deep-sea depression (Berlin and Ulmishek, 1978b). Each sandy bed pinches out to the northeast but is easily traced for some distance to the west. Where the bed becomes inclined on the slope of the depression, the sandstones give way to shales. Each upper sandy bed can be traced to the west for a longer distance than the subjacent one.

Clayey beds of the Maykop Series are rich in dispersed organic matter, mainly of the sapropelic type; organic carbon content ranges from 0.5% to 2% and more. It is believed (Volobuyev et al., 1978; Miroshnikov et al., 1978) that these beds, together with the Kuma formation, were the source of oils for Upper Cretaceous pools of the Terek-Sunzha region, for pools in Albian stratum I in the Prikumsk region, and for some of the oils in the Cenozoic sedimentary rocks.

Productivity of the Maykop sequence is associated mostly with the lowermost horizon (Khadum), which contains large gas pools on the Stavropol arch. Reservoir sandstones and siltstones are spread over a relatively narrow zone along the eastern flank of the arch, evidently on the slope of the deep-sea depression. They thin rapidly to the center of the depression, where they are replaced by shales and marls. In the rest of the Eastern Cis-Caucasus, the Maykop Series contains relatively rare, small pools of oil. The lack of pools can be explained by the specific hydrodynamic conditions in the series; that is, each sandy bed in the sequence is a large lens. Since a formation-wide hydrodynamic system is absent, migration and accumulation of oil was prevented.

The Maykop Series greatly influenced oil and gas generation and concentration in the Eastern Cis-Caucasus and presumably in the Caspian Sea area as well. Throughout subsequent geological history, the series formed a thick, regional, impermeable seal that prevented destruction of pools during neotectonic movements. In addition, it was a heat-resistant sequence that helped create conditions favorable for the generation of oil in underlying sequences.

3.9 MIDDLE MIOCENE-EARLY PLIOCENE

At the end of the early Miocene, the sea retreated from the entire region. Large-scale tectonic movements occurred in the Great Caucasus Mountains and adjacent platform. These movements were especially significant east of the Caspian Sea, where they created present-day structural features. At the beginning of the middle Miocene (see Fig. 25), the sea again flooded the greatly subsided foredeep. As the transgression advanced slowly toward the north and northeast, up to 1500 m of middle Miocene sands and clays were deposited in the axial portion of the foredeep. The thickness of these sediments decreased rapidly to the north.

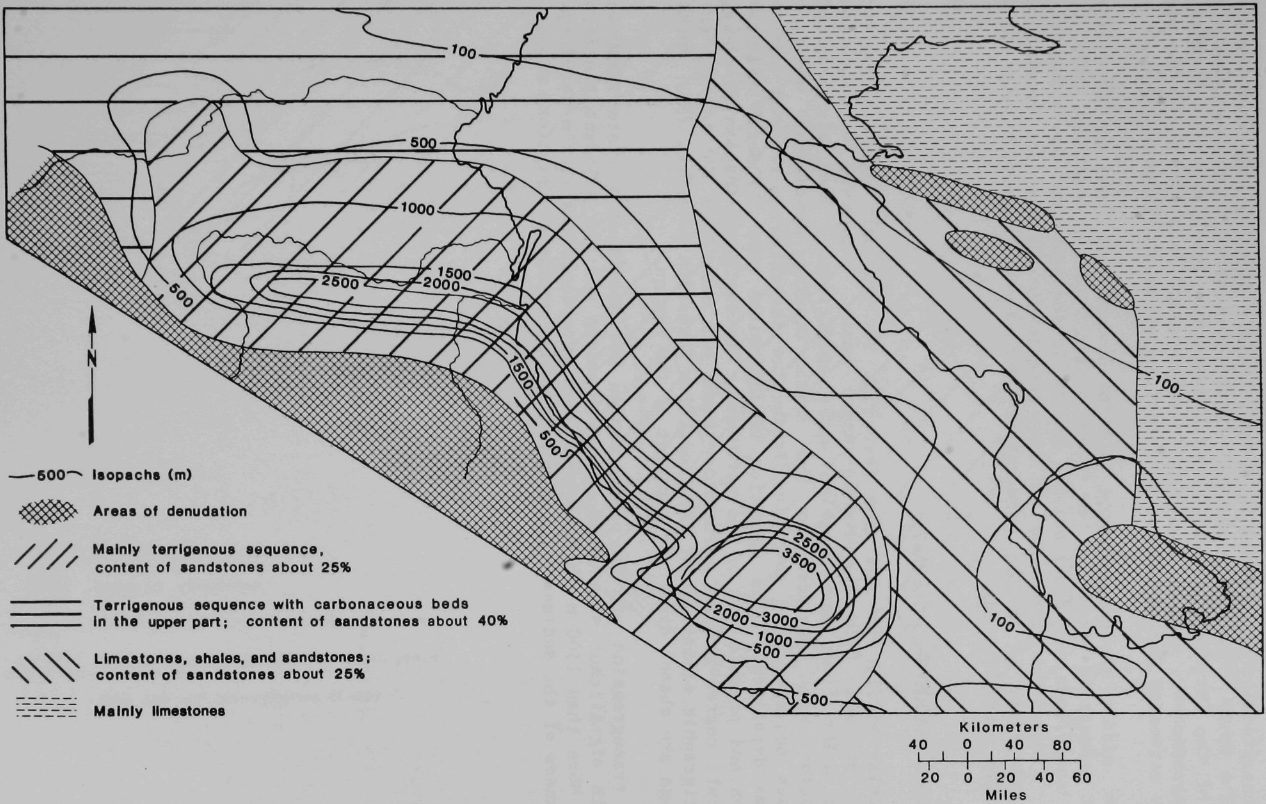


Fig. 25 Facies Map of Middle Miocene-Lower Pliocene Sedimentary Rocks (Sources: Compiled from Berlin et al., 1978a, and Polster et al., 1972)

Transgression was maximum in Sarmatian (late Miocene) time when the sea flooded the North Ustyurt depression. (Limestones of this age now cover the surface of the Ustyurt plateau, thereby preventing its erosion.) A thick, clastic-carbonaceous molasse continued to accumulate in the foredeep. The sea gradually retreated during the end of Sarmatian and early Pliocene time.

The middle Miocene sequence (Chokrak and Karagan horizons) contains important productive strata in the Terek-Caspian foredeep (see Fig. 23). Up to 20-25 sandy beds are distinguished in the Terek-Sunzha and South Dagestan regions. Reservoir properties of the sandstones usually are excellent. Porosity generally is 18-25%; permeability varies widely, but is high as a rule and may reach 3500 md.

3.10 MIDDLE PLIOCENE-QUATERNARY

During middle Pliocene time (see Fig. 26) the paleo-Caspian Sea was separated by land from the Mediterranean basin. Molasse sedimentation continued under fresh and brackish water conditions. The main area of sedimentation was displaced to the South Caspian depression where a terrigenous sequence, the so-called Productive formation, more than 6000 m thick, was deposited. This formation was deposited over the North Apsheron depression and pinches out to the northeast. In the Terek-Caspian foredeep, terrestrial, coarse-grained sedimentary rocks not more than 300 m thick are the stratigraphic equivalent of the Productive formation (see Fig. 23). Rocks of this age are absent over the remainder of the region.

A transgression of the paleo-Caspian Sea developed in late Pliocene time, with significant subsidence of the foredeep and the adjacent platform margin. More than 1500 m of sands and clays were deposited in the foredeep. The thickness of the sediments decreased gradually across the platform slope.

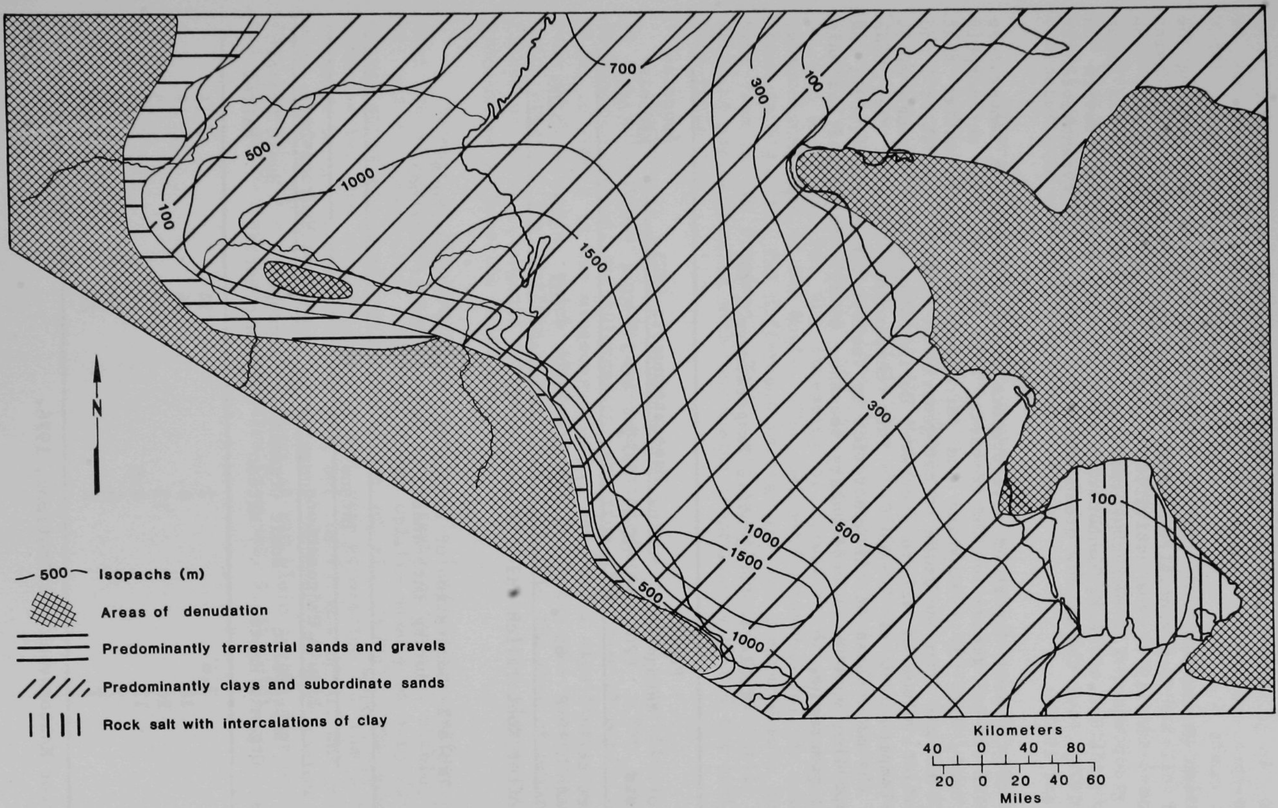


Fig. 26 Facies Map of Middle Pliocene-Quaternary Sedimentary Rocks (Source: After Polster et al., 1972)

4 STAGES OF OIL AND GAS GENERATION

Russian geologists have achieved significant progress in assessing the volumes of oil and gas generated during the geological history of a basin. This is due primarily to the activities of three groups of geologists: the Leningrad group under S.G. Neruchev (Neruchev, 1969), the West Siberia group under A.A. Trofimuk and A.E. Kontorovich (Kontorovich, 1970; Kontorovich and Trofimuk, 1976), and the Moscow group under N.B. Vassoyevich (Vassoyevich et al., 1969 and 1971).

Two of the most important developments are: (1) using a temperature scale for oil and gas generation and comparing this scale with the metamorphic grade of coal, and (2) evaluating the percentage of organic matter that becomes oil and gas from one grade of catagenesis to another (see Tables 1 and 2). The major volume of oil is generated during stages MC-1 through MC-3, i.e., at temperatures of 90-160°C. This temperature "window" has been designated the main phase of oil generation by Vassoyevich et al. (1969), and the corresponding part of a sedimentary sequence usually is called the main zone of oil generation.

Table 1 Catagenesis Temperatures (°C)

Grade of Catagenesis	Proto-catagenesis (PC)	Mesocatagenesis (MC)					Apocata-genesis (AC)
		MC-1	MC-2	MC-3	MC-4	MC-5	
Temperature at end of grade	65	90	135	160	185	200	>200

Source: After Kontorovich and Trofimuk, 1976.

Table 2 Generation of Liquid and Gaseous Hydrocarbons during Catagenesis of Organic Matter (kg/ton)

Grade of Catagenesis	Intensity of Generation			
	Liquid Hydrocarbons		Gaseous Hydrocarbons	
	Sapropelic Organic Matter	Humic Organic Matter	Sapropelic Organic Matter	Humic Organic Matter
PC	3.6	2	24	16
MC_1	16	8	26	19
MC_2	20	12	24	15
MC_3	13	4.6	18	10
MC_4	7	4	14	9
MC_5	7	2	22	15

Source: After Kontorovich and Trofimuk, 1976.

Figure 27 is a reconstruction, prior to the beginning of catagenesis, of the amount of organic matter in the Bajocian-Bathonian sequence of the Middle Caspian Basin. Subsurface data were used for land areas and paleogeographic extrapolations for offshore areas. The amount of organic matter in a given column depends on its content in the individual members and the thicknesses of the members. Maximum amounts are associated with the large Mesozoic depressions, such as the slope of the Great Caucasus geosyncline, the Kazakh and Zhazgurly depressions, and the Kizlyar Bay depression. Sapropelic organic matter predominates in marine sediments, while humus-type matter is more characteristic of rocks of nonmarine origin.

Figure 28 shows the oil generation process in the Bajocian-Bathonian sequence. Evaluation of grades of catagenesis is based on inferred paleotemperatures in the beds. The depth of subsidence of the Bajocian-Bathonian sequence and the reconstructed geothermal properties of the rocks were used for this inference. During the first two stages (Fig. 28, a and b), oil generation was confined mainly by the Great Caucasus miogeosyncline and adjacent parts of the platform slope (including the Cis-Dagestan downwarp). During the next two stages (Fig. 28, c and d), oil generation was widespread on the platform, but the intensity of formation decreased sharply in the geosynclinal part of the basin. The analogous situation for gas generation is shown in Fig. 29. The difference is that gas was generated more consistently over time in the foredeep. This could be attributed to gradually decreasing rates of gas generation with increasing temperatures toward the platform areas (see Table 2).

Three main factors influence the volume of oil generation. The first is the thicknesses of the oil-generating formations. (For the Bajocian-Bathonian sequence, the thicknesses vary from a few tens of meters on platform highs to 2000 m in the miogeosyncline). The second significant factor is the rate of subsidence, which differs greatly between the geosyncline and the inner areas of the platform. The third factor is the type of organic matter. (Based on Table 2, organic matter of the sapropelic type yields twice as much hydrocarbon as does the humic type.

In most of the central Caspian Sea, foci of oil generation of different ages are superimposed on each other to create an area of stable, continuing oil and gas generation. Adjacent large uplifts should be very favorable for accumulation of large pools (Geodekyan et al., 1978a). The same features characterize the history of oil and gas generation in the Aptian-Albian sequence of the Middle Caspian Basin, but the volumes of oil and gas generated were somewhat less, and the development of foci for hydrocarbon generation came somewhat later. Nearly all parts of the basin to the east of the Caspian Sea were unaffected by oil generation (see Sec. 9, Fig. 59).

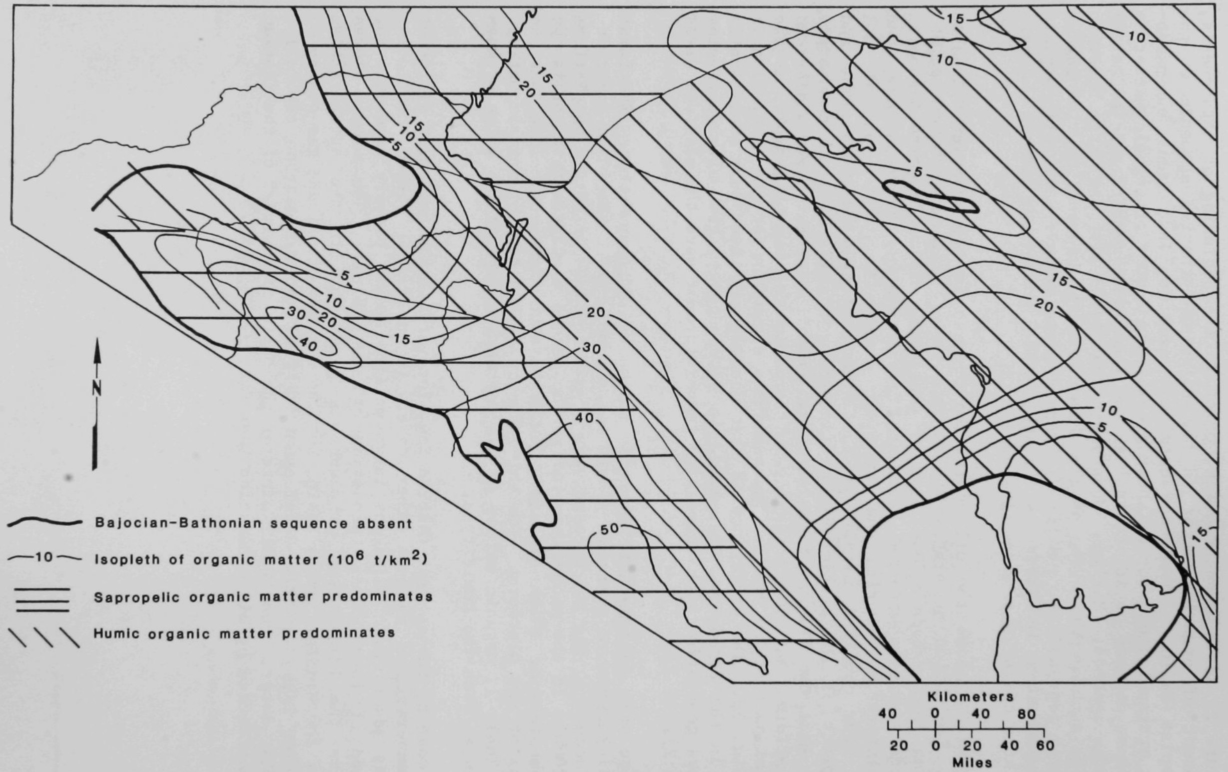


Fig. 27 Quantity of Dispersed Organic Matter in Bajocian-Bathonian Shales at the Beginning of Catagenesis (Source: After Geodekyan et al., 1978b)

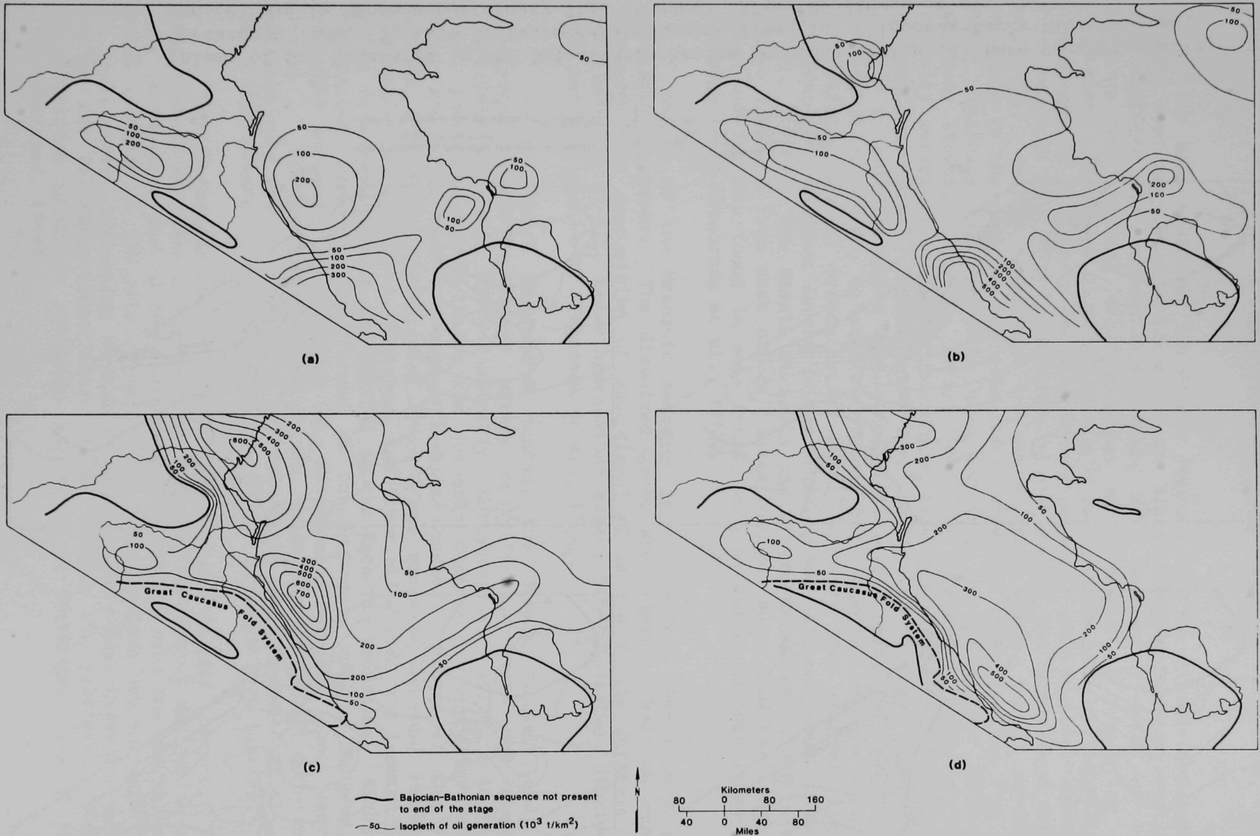


Fig. 28 Volume of Oil Generation in the Bajocian-Bathonian Sequence during (a) Late Jurassic-Early Cretaceous Time, (b) Late Cretaceous-Late Eocene Time, (c) Oligocene-Early Miocene Time, and (d) Middle Miocene-Quaternary Time (Source: After Geodekyan et al., 1978b)

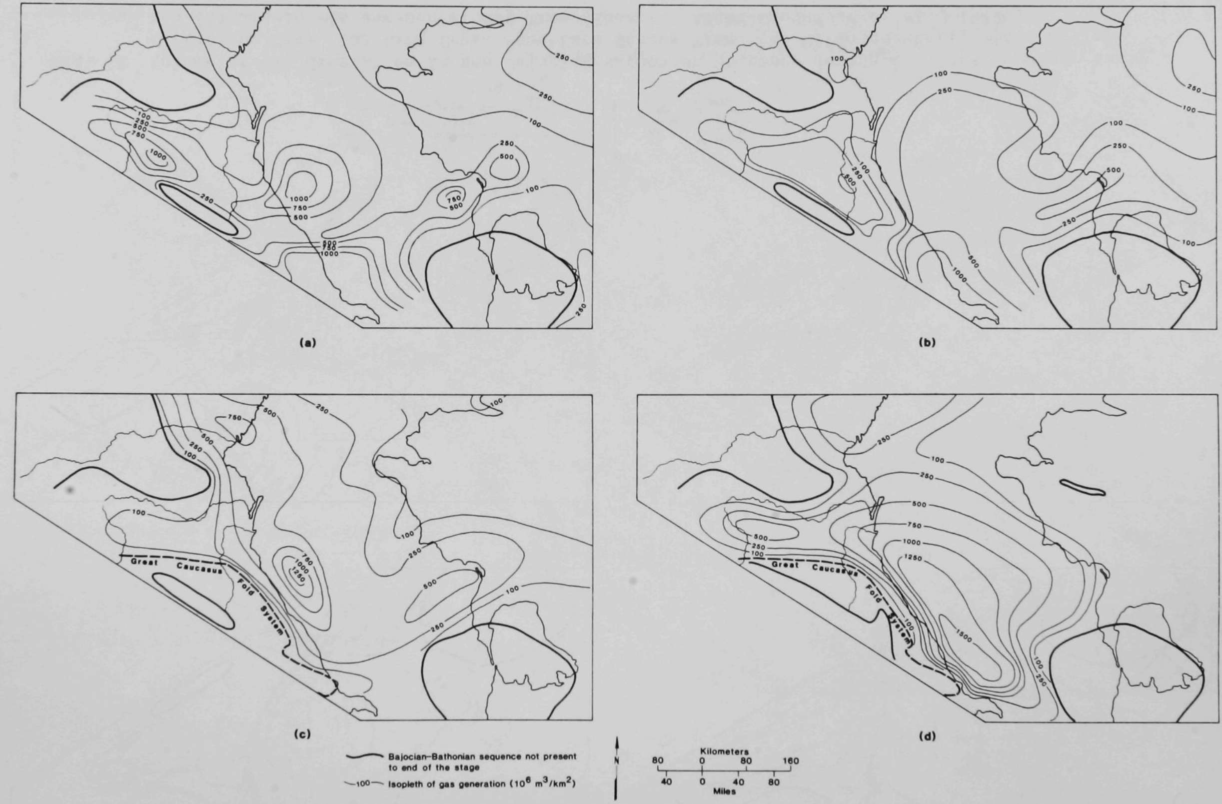


Fig. 29 Volume of Gas Generated in the Bajocian-Bathonian Sequence during (a) Late Jurassic-Early Cretaceous Time, (b) Late Cretaceous-Late Eocene Time, (c) Oligocene-Early Miocene Time, and (d) Middle Miocene-Quaternary Time (Source: After Geodekyan et al., 1978b)

5 MAIN HYDROGEOLOGICAL FEATURES

Two main aquifers, the Middle Jurassic and the Albian-Cenomanian, are present over most of the Middle Caspian Basin. Hydrogeological conditions in the aquifers are rather complicated, with coexisting zones of external recharge and internal water movement as a result of compacting plastic formations. External recharge occurs in the western part of the basin along the slopes of the Great Caucasus Mountains where both aquifers are exposed. This recharge zone is well expressed in the area of the Mineralovod swell (see Fig. 30). On the other part of the mountain slope, only a narrow strip adjacent to the exposures is affected by subaerial drainage (see Figs. 30 and 31). Salinity and hydraulic head increase sharply in the Terek-Caspian foredeep (Volobuev et al., 1978). With the exception of this strip, high-salinity waters of the chlorine-calcium type are widely distributed in both Mesozoic aquifers. These waters are characterized by an almost complete absence of sulfates and a high concentration of bromine and iodine. In the Eastern Cis-Caucasus, an aquifer system that "exports" connate water up-dip (centrifugal system) predominates, and anomalously high reservoir pressures are developed at great depths in the foredeep and adjacent areas (Miroshnikov et al., 1978). The Middle Jurassic and Albian-Cenomanian aquifers are not always isolated from each other. Interflows of water from the lower to the upper aquifer are found in some areas, such as the Karpinskiy ridge and the Prikumsk swell (Yegorova et al., 1974).

Waters of the Mesozoic sequence in the Eastern Cis-Caucasus are not saturated by gases. The dissolved gases are primarily hydrocarbons. The characteristic composition of gas dissolved in the Middle Jurassic aquifer is: methane, 61-95%; heavy hydrocarbon gases, 5.5-24%; carbon dioxide, 0.4-29%; and nitrogen, 1-9% (Yegorova et al., 1974).

In the South Mangyshlak region, the Middle Jurassic and Albian-Cenomanian aquifers contain waters of different types and are almost completely separated hydrodynamically (Kortsenshtein, 1972). At the same time, producing strata inside the Jurassic aquifer are connected with each other and often have a common oil-water contact. Waters of the Jurassic aquifer are highly concentrated brines, and zones of external recharge are almost absent. The Uzen, Zhetybay, and other oil fields are located only 20-40 km from exposures of the aquifer in the Kara-Tau Mountains. Although the present-day structure was formed at the beginning of the Neogene, these petroleum accumulations have not been destroyed. However, local, very narrow strips of freshened inflow water are evidently connected with zones of comparatively high fracturing in the Uzen field (Melik-Pashaev et al., 1973). Where this occurs, there is destruction of oil deposits by oxidation.

The Cretaceous aquifer contains brines of low salt content. This low salt content is found in the vast area around the Central Mangyshlak uplifts. Only in the deep part of the South Mangyshlak trough does the concentration of salts increase to 150 g/L. However, the concentration may increase somewhat in local areas, indicating windows of comparatively high hydraulic conductivity of the Oxfordian-Kimmeridgian shales between the aquifers. Such salt-concentration anomalies accompany gas pools in Cretaceous beds of the Uzen field (Morozov, 1969).

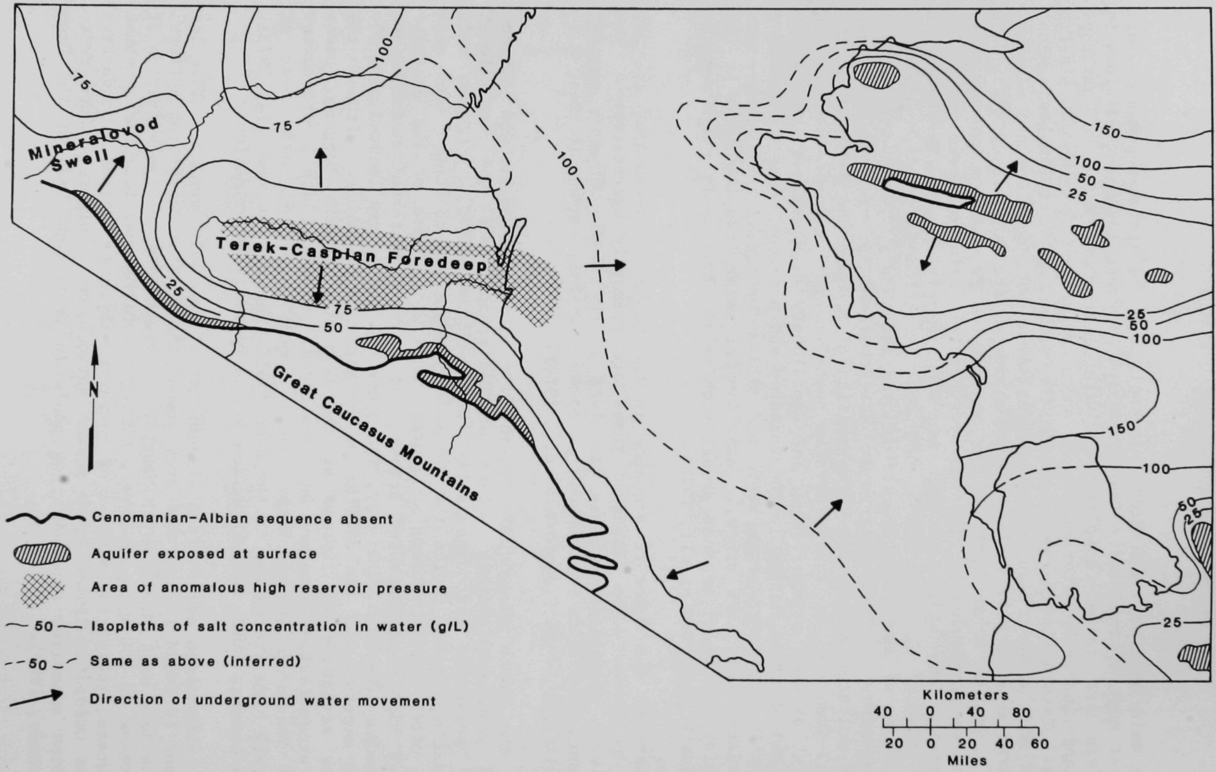


Fig. 30 Present-Day Hydrogeological Regime in the Albian-Cenomanian Aquifer Systems (Source: After Geodekyan and Pilyak, 1978)

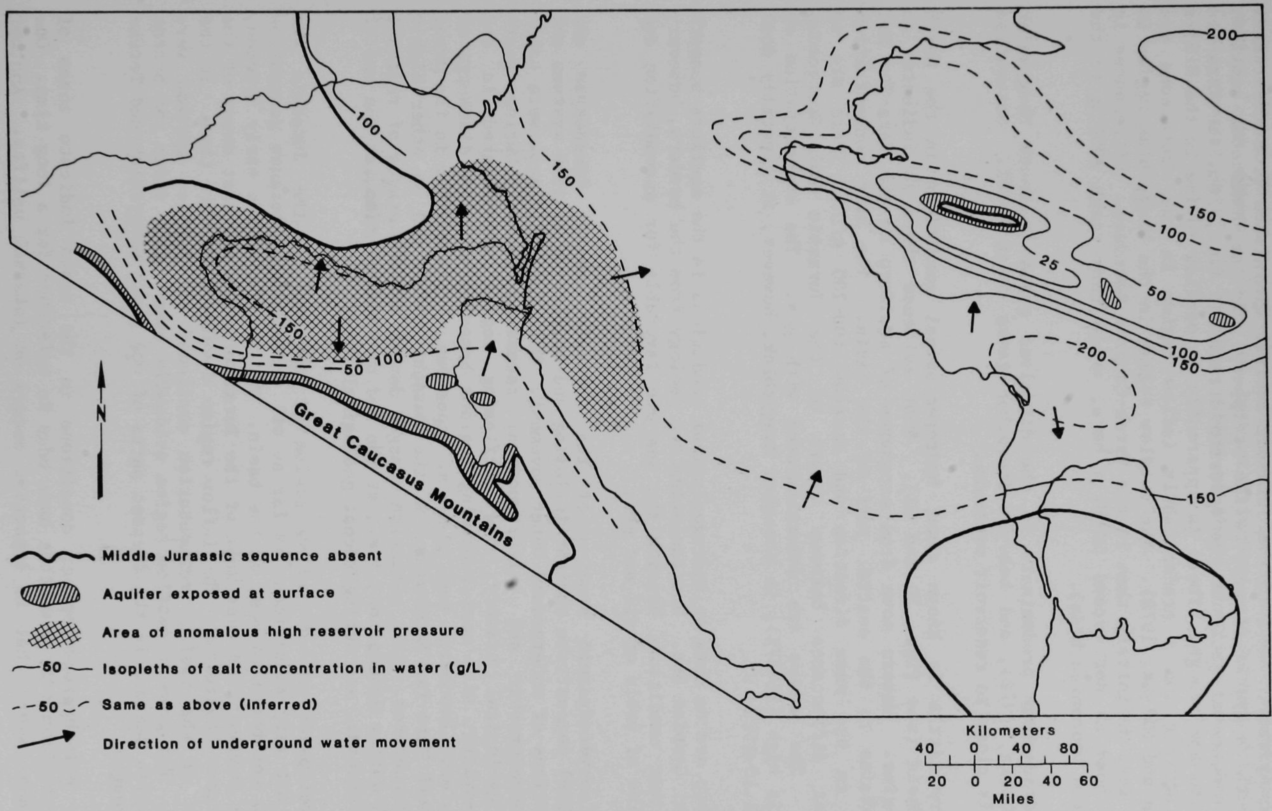


Fig. 31 Present-Day Hydrogeological Regime in the Middle Jurassic Aquifer System (Source: After Geodekyan and Pilyak, 1978)

The hydraulic head in the Jurassic aquifer diminishes from the center of the South Mangyshlak trough to its periphery. In the Cretaceous aquifer, the head reduces slightly in the opposite direction, i.e., from the Kara-Tau Mountains to the trough. There is apparently an outflow regime in the Middle Jurassic aquifer and a predominantly inflow regime in the Cretaceous one (Geodekyan and Pilyak, 1978). The outflow regime in the Mangyshlak region is expressed less definitely than in the Terek-Caspian foredeep. Differences in hydraulic head do not exceed 50-60 m here, while they reach 2000 m in the foredeep (in Neocomian beds).

Hydrocarbons predominate in the dissolved gases in South Mangyshlak (Kortsenshtein, 1972), and heavy hydrocarbon gases reach 5-10%. Saturation pressure is close to reservoir pressure.

Very little is known about hydrogeological conditions in the North Ustyurt Basin (see Figs. 30 and 31). What evidence there is indicates an inflow regime. Waters move from exposures of aquifers on the Kara-Tau and Ural Mountains to the central part of the basin. The salt concentration increases in the same direction and exceeds 100-200 g/L. There are no significant differences between waters of the Jurassic and Cretaceous aquifers. The waters are undersaturated with gas. The concentration of nitrogen is high (21-57%); in southern Mangyshlak, however, it generally does not exceed 10-15%.

There are no data on hydrogeological conditions in the aquifers beneath the central Caspian Sea. Extrapolating the geology from the borders, however, suggests that conditions beneath the sea are favorable for accumulation and conservation of pools of oil and gas.

Paleohydrodynamic studies of the Jurassic aquifer (Geodekyan and Pilyak, 1978) demonstrate ancient inflowing and outflowing aquifer systems and give directions of underground water movement. Data for their maps were taken from paleogeographic and paleostructural reconstructions. During post-Jurassic geological history, the outflowing regime predominated in the Jurassic aquifer, with most subsiding regions becoming areas of discharge of connate water. Discharge took place at exposures of the aquifer in the Great Caucasus and Kara-Tau Mountains, on the Buzachi swell, and on other highly elevated structures. This situation changed during various stages of regional uplift and during denudation, i.e., at the end of Jurassic time, at the end of the early Miocene, and during recent geological time.

Development of an inflow regime at the end of the Jurassic was evidently not very significant as far as oil accumulation, because generation of oil had not begun in most of the basin. At the end of the early Miocene, denudation predominated over most of the Turanian plate and vast areas of the Great Caucasus Mountains. The inflow regime developed at this time. In the other part of the basin, sedimentation continued and outflow systems were preserved. The present outflow regime evidently takes place under the bottom of the Caspian Sea and in the deepest parts of the South Mangyshlak and Terek-Caspian troughs.

The paleohydrogeological conditions in the basin indicate zones of regional potentiometric lows that have been in existence for a long time. One type of these zones that is important occurs on internal uplifts. Another type is found at the contact between upward-moving connate water and downward-moving fresh water. These two low-potentiometric zones were very favorable for accumulation of oil and gas. Some of these zones are discussed futher in Sec. 9.

6 PRODUCING REGIONS OF THE MIDDLE CASPIAN BASIN

The Middle Caspian Basin contains more than 100 oil and gas fields (see Fig. 32) ranging in size from small to supergiant. Groups of fields associated with a regional structural unit usually have many common features and may be considered to constitute a producing region. Eight producing regions are designated in the Middle Caspian Basin and part of the adjacent North Ustyurt Basin (see Fig. 32 and Table 3).

The North Stavropol producing region (I) embraces the northernmost part of the Stavropol arch. Fourteen gas fields are located here, the most important of which are the North Stavropol-Pelagiadinskoye and the Takhta-Kugultinskoye fields. The former contains about 220 x 10^9 m^3 of gas and constitutes two-thirds of the reserves of the region (Aleksin and Korotkov, 1964). The field occurs on a large structural closure (see Fig. 33) that complicates the Stavropol arch. The main producing horizon is the lowermost part of the Maykop Series (Oligocene-early Miocene). The initial open flow of dry gas exceeded 8.5 x 10^6 m^3/d. Thickness of the pay zone reaches 120 m. Porosity of the coarse-grained siltstones of the horizon approaches 22%, and permeability approaches 2000 md. A lesser gas pool is contained in the Chokrak and Karagan horizons (middle Miocene). Since the degree of exploration in the North Stavropol region is extremely high, discovery of significant new reserves is very unlikely.

The Arzgir-Prikumsk producing region (II) (see Fig. 32) is east of the Stavropol arch, and occupies mainly the Arzgir uplift and the Prikumsk swell. Several medium-sized gas fields are located on the Arzgir uplift. Gas-producing zones occur in the Lower Cretaceous rocks (92% of reserves) at depths of 2500-3000 m (Dikenshtein et al., 1977). The degree of exploration here is high also.

More than 50 oil and gas-condensate fields have been found on the Prikumsk swell and in adjacent areas. The fields are controlled by low-amplitude brachyanticlines grouped in three elongated uplifts. Oil fields predominate, and gas-condensate pools appear mainly on the eastern plunge of the swell. Although almost all of the sequence is producing, 80% of the reserves are associated with Lower Cretaceous strata at a depth of 2500-4000 m, and Jurassic beds accounts for 15% of the reserves (Dikenshtein et al., 1977). In the Lower Cretaceous sequence, up to 13 producing strata are recognized. Major pools in the Arzgir-Prikumsk region (see Fig. 34) occur in strata of Neocomian-lower Aptian (strata XIII-VIII) and Albian (stratum I) age (Aleksin et al., 1979). Most of the fields are of small to medium size, the most important among them being Ozek-Suat, Zimnyaya Stavka, and Velichayevka. Reserves of the largest, the Ozek-Suat field, are estimated to be about 65 x 10^6 t (The Petroleum Industry in the USSR, undated). Most of the small fields contain several million tons of oil.

Two types of oil are distinguished in the region: a methane-type in the lower part of the sequence (Triassic through stratum IV of the Lower Albian), and a methane-naphthene type in the upper part (stratum I of the Upper Albian-Cenozoic). In methane-type oils, the degree of catagenic transformation increases with the depth and age of the rocks. In addition, the content of methane series hydrocarbons, the paraffin content (up to 40%),

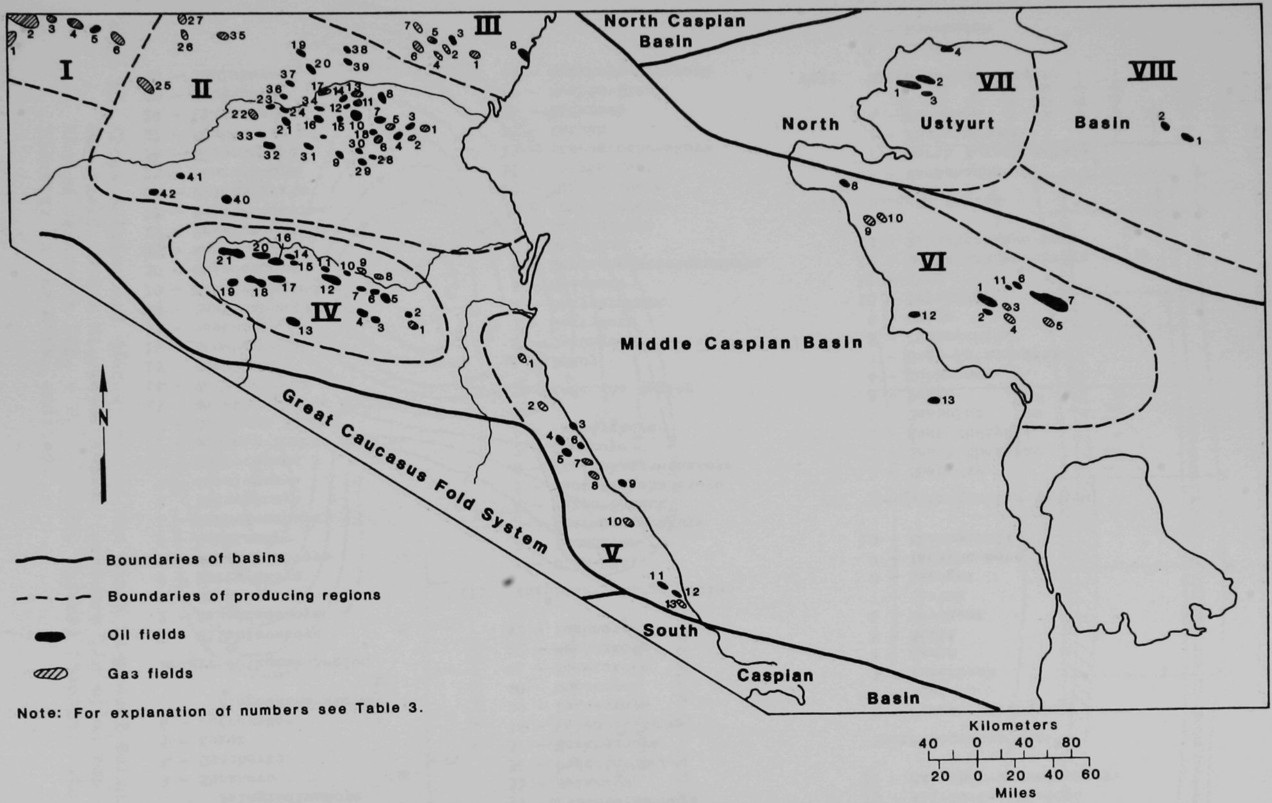


Fig. 32 Producing Regions of the Middle Caspian Basin and Part of the Adjacent North Ustyurt Basin

Table 3 Oil and Gas Fields of the Middle Caspian Basin

I North Stavropol Region

1 - Sengeleevskoye
2 - North Stavropol-Pelagiadinskoye
3 - Shpakovo
4 - Grachevka
5 - Kugut
6 - Petrovsko-Blagodarnenskoye

II Arzgir-Prikumsk Region

1 - Ullubievskoye
2 - Dagestanskoye
3 - Stepnoye
4 - Martovskoye
5 - Solonchakovoye
6 - Ravninnoye
7 - Sukhokumskoye
8 - Solnechnoye
9 - Granichnoye
10 - Vostochnoye
11 - Russkiy Khutor Central
12 - Zimnyaya Stavka
13 - Russkiy Khutor Northern
14 - Velichayevka
15 - Ozek-Suat
16 - Urozhaynoye
17 - Voskhod
18 - Dakhadaevka
19 - Maksimokumskoye
20 - Kolodeznoye
21 - Achikulak
22 - Praskoveyskoye
23 - Pravokumskoye
24 - Vladimirovka
25 - Zhuravskoye
26 - Mirnenskoye
27 - Kucherlinskoye
28 - Kaliyevskoye
29 - Tyubinskoye
30 - Stalskoye
31 - Mekteb
32 - Lesnoye
33 - South Achikulak
34 - Pravoberezhnoye
35 - Selskoye
36 - Podsolnechnoye
37 - Sovkhoznoye
38 - Konsonolskoye
39 - Zakumskoye
40 - Kurskoye
41 - Sovetskoye
42 - Marinskoye
43 - Yuzhnoye

III Karpinskiy Ridge Region

1 - Ulan-Khol
2 - Yermolino
3 - Chernozemelskoye
4 - Naryn-Khuduk
5 - East Kamyshanskoye
6 - Krasnokamyshanskoye
7 - Krasnoye
8 - Kaspiyskoye

IV Terek-Sunzha Region

1 - Benoy
2 - Oysungur
3 - Goyt-Kort
4 - Oktyabrskoye
5 - Gudermes
6 - Goryacheistochnenskoye
7 - Abu-Yurt
8 - Bragunskoye
9 - Chervlennoye
10 - Yastrebinoye
11 - Khayan-Kort
12 - Starogroznenskoye
13 - Katykh
14 - Eldarovo
15 - Muzhim-Biruk
16 - Gorskoye-Orlinoye
17 - Sernovodskoye
18 - Karabulak-Achaluki
19 - Zamankul
20 - Ali-Yurt-Alkhazovo
21 - Malgobek-Voznesenskoye

South Dagestan Region

1 - Makhachkalinskoye
2 - Achi-Su
3 - Izberbash
4 - Gasha
5 - Selli
6 - Kayakent
7 - Duzlak
8 - Dagogni
9 - Inchkhe-more
10 - Khoshmenzil

VI South Mangyshlak Region

1 - Zhetybay
2 - South Zhetybay
3 - East Zhetybay
4 - Tasbulat
5 - Tenge
6 - Turkmenoy
7 - Uzen-Karamandybas
8 - Tyubedzhik
9 - Dunga
10 - Espelisay
11 - Asar
12 - North Rakushechnoye
13 - Rakushechnoye-more

VII Buzachi Region

1 - Karazhanbas
2 - North Buzachinskoye
3 - Zhalgiztyube
4 - Kalamkas

VIII North Ustyurt Region

1 - Arystan
2 - Karakuduk

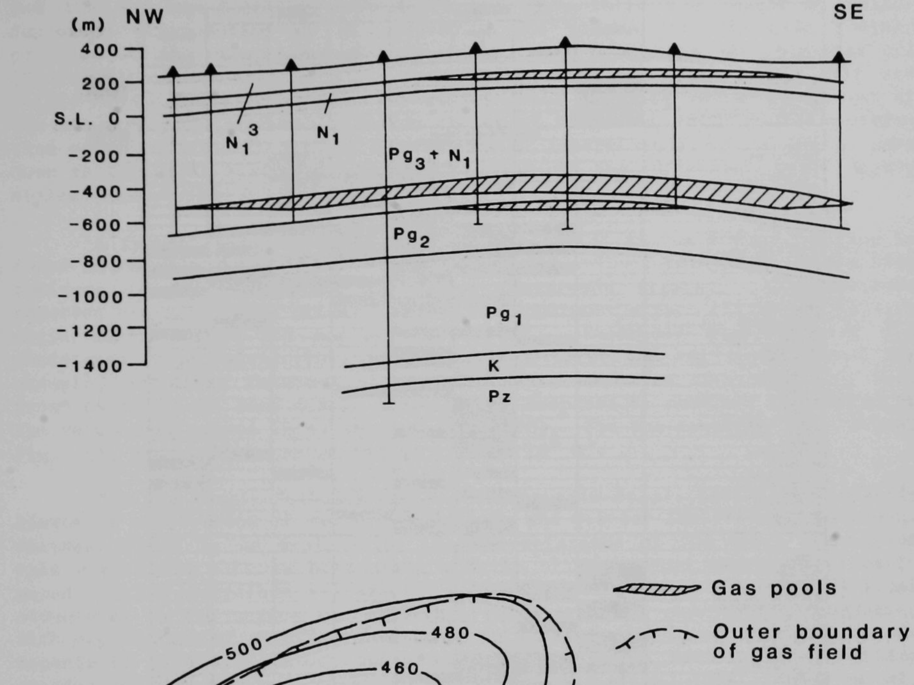


Fig. 33 Cross Section and Contour Map of the North Stavropol-Pelagiadinskoye Gas Field, North Stavropol Region (contours [in m] on top of the Khadum reservoir ($Pg_3 + N_1^1$ - Maykop Series) (Source: The Petroleum Industry in the USSR, undated)

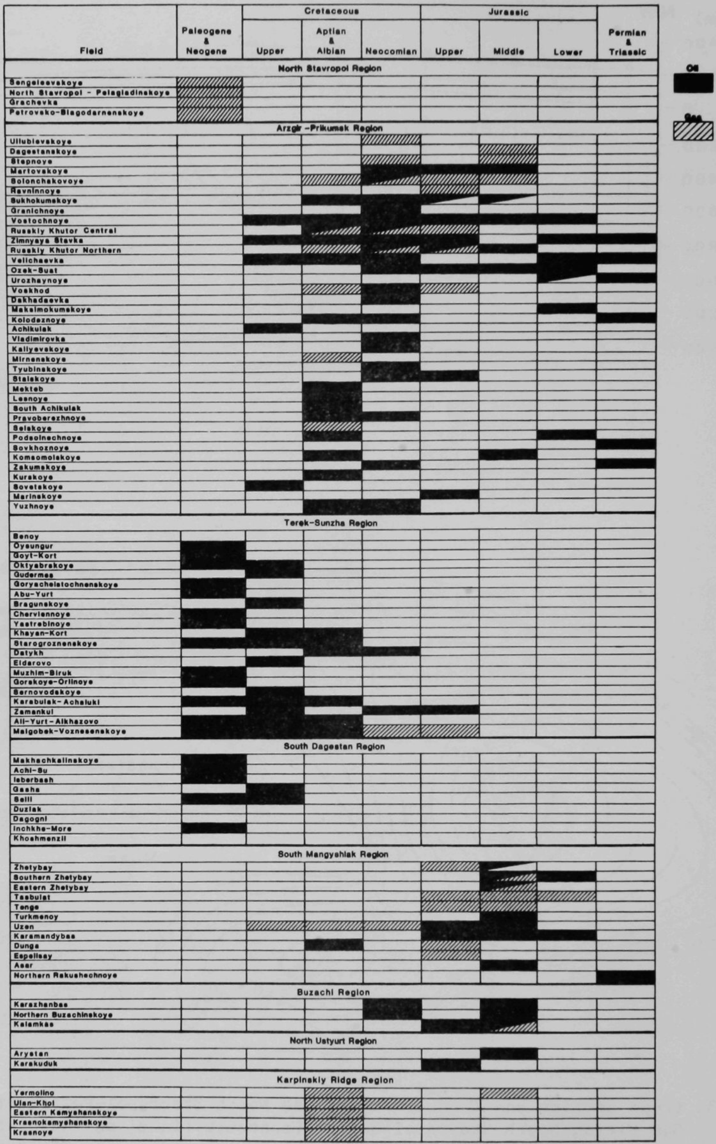


Fig. 34 Stratigraphic Distribution of Oil and Gas Pools

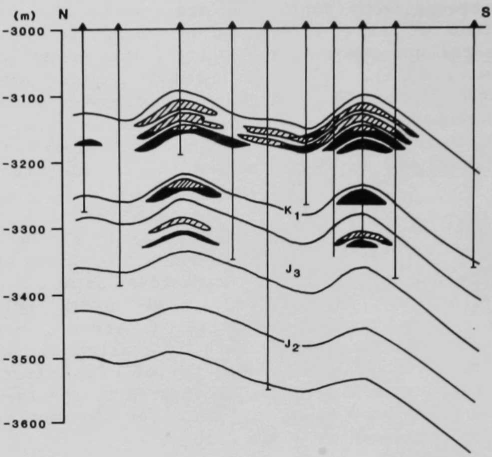
and the density increase with depth and age, while the amount of sulfur decreases (Miroshnikov et al., 1978). The oldest Triassic oils contain products of deep-seated catagenesis, e.g., light condensate and high-tar oil (Sharafutdinov et al., 1975). The source rocks for methane-type oils are mainly Middle Jurassic rocks. The source rocks for oils in the upper part of the sequence were presumably Maykop shales of Oligocene age. Downward migration of oil was facilitated by the absence of impervious rocks in the sequence down to the Upper Albian and by high pressure in the thick sequence of Maykop shales (Miroshnikov et al., 1978).

A typical example of the oil and gas fields in the Prikumsk region is found in the Russkiy Khutor field (see Fig. 35). It contains seven productive horizons in Upper Jurassic and Lower Cretaceous strata. Gas-condensate reserves are associated primarily with the uppermost strata ($VIII_1$ and $VIII_2$), while other strata are mostly oil-bearing. Reservoir properties of the sandstones show considerable variation both laterally and vertically. For example, petroleum reserves of gas-condensate pools in strata $VIII_{1-2}$ were found to be 30-35% less during exploitation compared to reserves calculated by the volumetric method (Erbolatov et al., 1978). For the southern closure (see Fig. 35), reserves are estimated at $3-3.5 \times 10^9$ m^3.

For the Arzgir-Prikumsk region, Dikenshtein et al. (1977) give coefficients of exploration of 0.6 for the Arzgir and 0.5 for the Prikumsk portions. Although there is no explanation in this reference of the exact meaning of this coefficient, it is presumably a ratio of discovered resources to estimated initial petroleum resources. Although there is a lack of anticlinal structures in the region for drilling, there are high expectations connected with exploration of stratigraphic traps in Jurassic and Lower Cretaceous beds, especially in the pinch-out zones along the Stavropol arch and the southern portion of the Prikumsk swell (Burshtar and Manuylova, 1978; Chepak et al, 1977). However, several well-transects across this zone have not given positive results as yet. Another target for exploration is the Triassic section, mostly in the East Manych trough and along its borders. At present only 1% of the proved reserves of the region are in Triassic pools, but about 40% of future resources are presumed to be related to this complex of rocks (Dikenshtein et al., 1977). Thirty percent of these projected resources are assigned to the Jurassic, 27% to the Cretaceous, and 3% to the Paleogene sections.

Several fields producing mainly gas have been discovered in the Karpinskiy ridge region. Gentle anticlinal folds are grouped in two zones generally parallel to the trend of the major structure. The flanks of the folds are faulted into small blocks. Pools in the Lower Cretaceous (89% of reserves) and Jurassic (8% of reserves) sections are of small to medium size. Most of them contain a high percentage of heavy hydrocarbon gases, carbon dioxide, and nitrogen (Karpov and Raaben, 1978). Because the region has been thoroughly explored, important new discoveries are not expected.

The Terek-Sunzha region (see Fig. 32 and Table 4) occupies the axial portion of the Terek-Caspian foredeep and the adjacent platform slope of the foredeep. A striking characteristic of the region is the two large anticlinoriums -- the Terek (northern) and Sunzha (southern) -- which contain most of the fields. Some fields are located in the folds of the more northern and less-expressed Priterek uplift. The thickness of the Mesozoic-Cenozoic



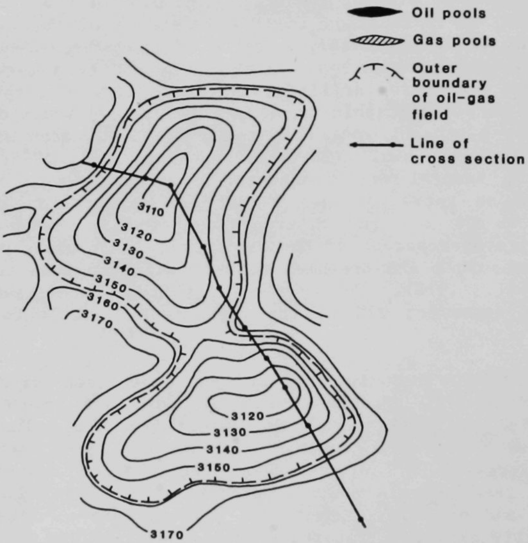


Fig. 35 Cross Section and Contour Map of the Russkiy Khutor Central Oil and Gas Field, Arzgir-Prikumsk Region (contours [in m] on top of producing stratum VIII [Lower Cretaceous]) (Source: The Petroleum Industry in the USSR, undated)

cover in the region exceeds 10 km, more than half of which is Cenozoic molasse. An important role in the formation of structures in the region belongs to diapiric tectonics in the Maykop shales. Diapirism of plastic, halogenic Upper Jurassic rocks also has been suggested. Because Middle and Lower Jurassic beds beneath the salt section have not been penetrated by wells, their structure is unknown. It is assumed that such structural closures do not coincide with the closures in the upper sequence and are displaced to the north of the Terek and to the south of the Sunzha ridges (Aleksin et al., 1979). Local anticlines on the ridges are characterized by very high closures (up to 1500 m in Mesozoic units) and, accordingly, by the large volume of the traps. Numerous faults complicate the structures.

Most fields in the Terek-Sunzha region contain oil pools; gas pools are subordinate. Pools are found in all strata from the Upper Jurassic to the upper Miocene (see Fig. 34), but the main reserves are concentrated in the middle Miocene Chokrak and Karagan horizons and in the Upper Cretaceous section (31% and 55%, respectively). Up to 24 reservoirs in the Miocene are in sandstone strata and are productive over an interval of 500-2200 m. In the Upper Cretaceous sequence, oil occurs in fractured limestones at depths of 1500-3900 m.

Oils from the Miocene and Upper Cretaceous pools are of different types (Grayzer, 1978). Oils of middle Miocene age are characterized by a predominance of naphthenes in the light fraction; development of hypergene processes is widespread in pools at depths of 1000 m. Only in the southern part of the foredeep, at depths of 1000-3000 m, are there light oils with a density of 0.830-0.860 g/cm^3 and with low tar content. Upper Cretaceous oils are of the methane-naphthene type. Since the composition of the oils is not correlated with their conditions of occurrence, different sources for these two types of oils have been postulated: lower Maykop and possibly Mesozoic rocks have been postulated for the Upper Cretaceous oils, and middle Miocene bituminous shales have been postulated for the oils in the Miocene pools.

The most important field in the region is the Malgobek-Voznesenskoye field (see Fig. 36). Its recoverable reserves are estimated at about 400×10^6 t of oil (Halbouty et al., 1970). The field occurs in a steep, elongated anticline complicated by overthrusts. The major productive horizon is in Upper Cretaceous limestones. Smaller pools are found in the Lower Cretaceous and Upper Jurassic. Relatively small pools in the Chokrak and Karagan horizons of middle Miocene age, at depths of a few hundred meters, are now mainly depleted.

The main prospects in the region are at depths of about 5000-7000 m in the Middle Jurassic section beneath the salt (70% of estimated resources) and in the Cretaceous section (25% of estimated resources) (Dikenshtein et al., 1977). The coefficient of exploration is 0.6. Exploration has been delayed by the poor quality of geophysical data at great depths, by the occurrence of deformed plastic formations, and by complex tectonics. Future discoveries at these depths are expected to be mainly gas-condensate pools.

In the South Dagestan region (see Fig. 32), oil and gas accumulations are related to three anticlinal zones: Western, Eastern, and Maritime. The anticlinal folds are structurally complicated, and faults play an important role. Middle Miocene (Chokrak) and Oligocene sandstones, Upper Cretaceous

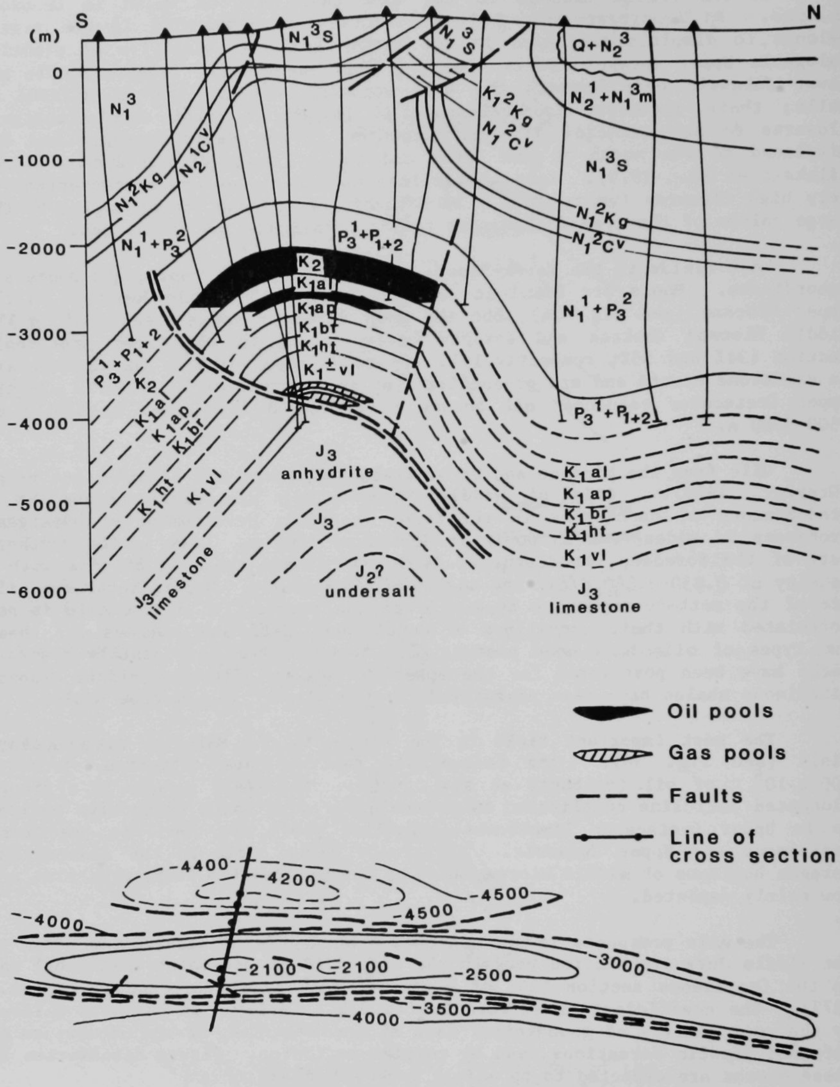


Fig. 36 Cross Section and Structural Map of the Malgobek-Voznesenskoye Oil Field, Terek-Sunzha Region (contours [in m] on top of Upper Cretaceous sedimentary rocks) (Source: After Aleksin et al., 1979)

limestones, and Aptian-Albian sandstones are productive, but the main reserves are in Chokrak and Upper Cretaceous strata. One offshore field, the Inchkhe-more, with production from Chokrak beds, has been found here. Several small, semicommercial fields with oil and gas pools have been located in upper Miocene, Oligocene, and to a lesser degree, in Upper Cretaceous strata. These pools occur in the southern part of the region in the Kusaro-Divichin depression. Most fields of the region are essentially depleted, and the prospects of discovering new resources onshore are very limited. However, significant resources are associated with the shallow offshore zone, where several structures are being explored.

The most important productive area in the eastern part of the Middle Caspian Basin is the South Mangyshlak region. This region will be described in more detail in Sec. 7.3.

Several possibly important discoveries have been made on the Buzachi peninsula during the last six years. This region was previously considered a poor prospect because of the relative thinness of the platform cover and the hydrogeological openness of the main producing beds. (The beds are exposed at the surface in relative proximity to the field.) The Buzachi region contains an archlike uplift of the same name and is located in the North Ustyurt Basin.

The most important of the four oil fields found here is the Karazhanbas field (see Fig. 37). Production of oil was first obtained from Neocomian rocks at a depth of 300 m. The free oil yield of the well was 150 m^3/d (Nurnanov and Gribkov, 1976). This field is associated with a rather large (30 km x 6 km) brachyanticline that is broken by a fault on its northern flank. Drilling has indicated that the structural interpretation based on seismic surveys was incorrect. The Lower Cretaceous sequence in the Karazhanbas field includes five pay zones 2-28 m thick. A small pool also was found in the upper part of the Jurassic section (Golov et al., 1979). Reservoir rocks consist of weakly cemented and friable sandstones and siltstones intercalated with shales. These rocks have an open porosity of up to 30%, permeabilities of a few to several hundred millidarcys, and oil saturations of about 25-45% (Khramova and Krivonos, 1977). Oil of the Karazhanbas field has a high density (0.94 g/cm^3), a high sulfur content (2%), and contains 15% tar and 6% asphaltene. The oil is of the naphthene type, containing 50% naphthene hydrocarbons. Methane-series hydrocarbons are present at 32.7% and aromatics at 11.4%. Because of the high viscosity of the oil (200 cp), polyacrylamide flooding has been considered (Ivanov et al., 1977).

Recoverable reserves of the Karazhanbas field are estimated at about 75×10^6 t. Development of this field will be difficult and the percentage of recoverable oil rather low. Primary recovery is expected to be 7% of the original oil in place (International Petroleum Encyclopedia, 1980). The shallow depth of the pool presents the Soviets with the interesting possibility of exploiting the field by mining. Such a petroleum mine has been under construction for the past few years at the old Balakhany field near Baku.

Other fields in the Buzachi region are smaller in size. The Kalamkas field has its pay zones in Jurassic beds at depths of more than 3000 m. These oil pools are beyond the hypergene zone, and the oil is less dense than that of the Karazhanbas field. This suggests that new fields may be discovered on the plunging flanks of the Buzachi uplift, including its offshore extension.

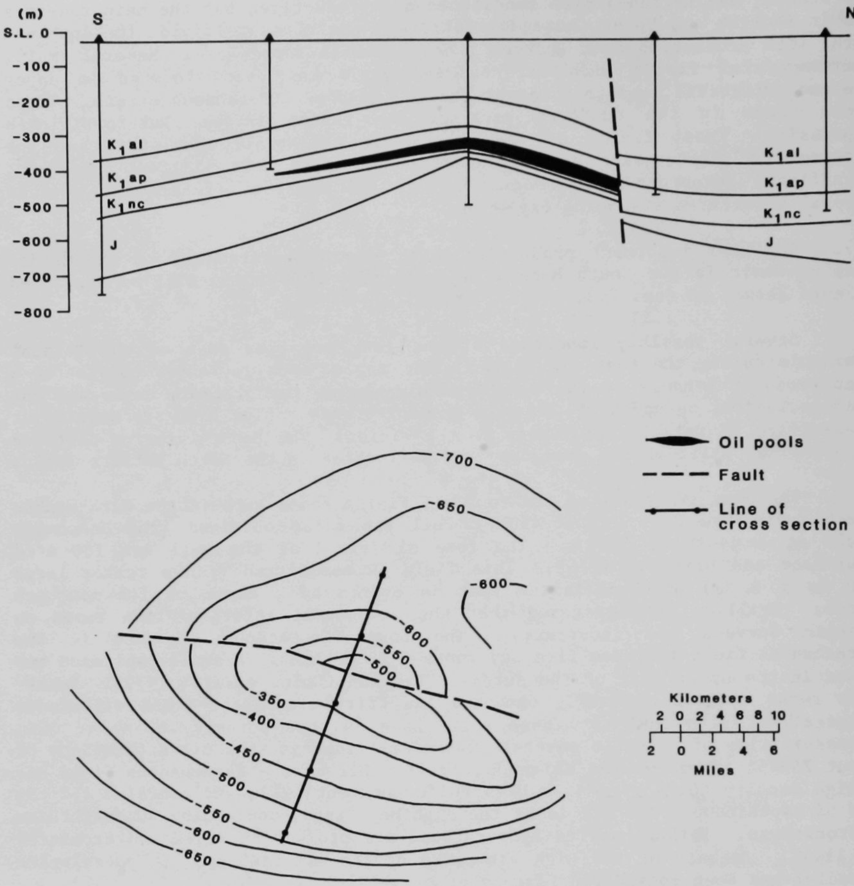


Fig. 37 Cross Section and Contour Map (preliminary data) for the Karazhanbas Oil Field, Buzachi Region (contours [in m] on top of the number III reflecting horizon [near the base of the Neocomian]) (Source: After Ozdoyev, 1977)

Oils of the Buzachi region are strikingly different from those of the Mangyshlak peninsula but are similar to those of the South Emba region. Fields in the South Emba region belong to the Precambrian platform, which is just off the northern edge of Fig. 32. Pre-Mesozoic sedimentary rocks are considered to be the source of these oils. Since the potential reserves of the Buzachi region are comparatively high, there is little doubt that new fields will be discovered here. Especially promising is the seaward-plunging continuation of the uplift. Prospects also look good for the Permian-Triassic section (Chakabayev et al., 1977a).

Two oil fields of relatively small size were discovered in the eastern part of the North Ustyurt region. The fields occur in anticlinal folds and contain several productive strata in the Jurassic sequence (see Fig. 38). Maximum yields obtained from wells were 127 m^3/d, although they usually did not exceed 10-20 m^3/d. Reservoir properties of the rocks are rather poor. Porosity is 11-13.5% and is not persistent laterally. Permeability usually is a few millidarcy and oil saturation is 55-60% (Ozdoyev, 1977). The oils are light (0.81-0.85 g/cm^3), contain small amounts of tar and sulfur, and have a high paraffin content. The hydrocarbons are predominantly of the methane series.

These fields in the North Ustyurt depression were discovered after about 10 yr of exploration activity. Several small gas fields also were found in a part of the depression outside the area of interest in this report. Prospects for the region are rated as comparatively low; this may be due in part to the lack of intense exploration (Chakabayev et al., 1977a). However, testing of the most promising Jurassic reservoir rocks in several fields in different parts of the depression did give negative results. The Permian-Triassic sequence consists of red beds, and suitable prospects for exploration were not found in these rocks. The underlying marine sequence of Carboniferous-early Permian age mainly occurs at great depths and its structure is unknown. Increased exploration activity in this region is not planned (Chakabayev et al., 1977a).

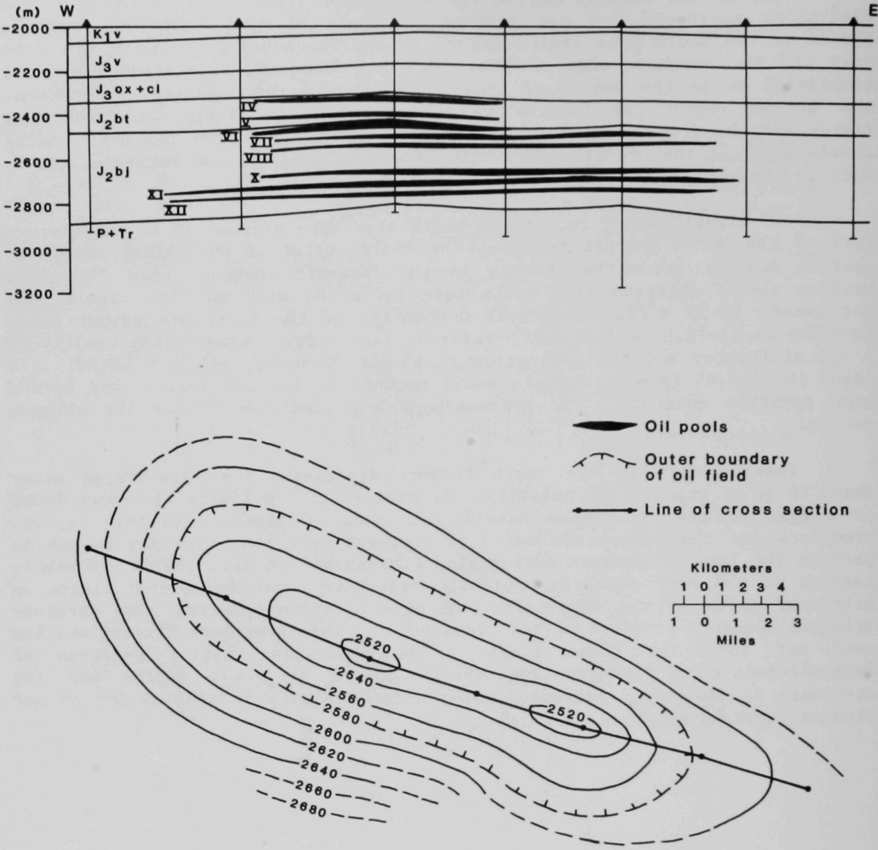


Fig. 38 Cross Section and Contour Map for the Arystan Oil Field, North Ustyurt Region (contours [in m] on top of the producing stratum VIII) (Source: After Ozdoyev, 1977)

7 THE SOUTH MANGYSHLAK TROUGH

The South Mangyshlak trough is now the most important oil-producing region of the Middle Caspian Basin. The trough is located in the western portion of the large South Mangyshlak-Ustyurt system of downwarps. It is more than 600 km long and 80-100 km wide.

7.1 STRUCTURE OF THE SEDIMENTARY COVER

The upper structural complex (platform cover) of the South Mangyshlak region can be subdivided into two subcomplexes: the lower (Jurassic through Paleogene) and the upper (middle Miocene through Quaternary). The thickness of the latter subcomplex is about 200 m and its attitude is approximately horizontal. It is separated from the underlying subcomplex by a regional angular unconformity.

Three main structures are recognized in the platform cover of the region (see Fig. 39): the South Mangyshlak trough, the Karabogaz arch to the south, and the Mangyshlak system of uplifts to the north. The main part of the Mangyshlak system of uplifts consists of two large swells -- the Tyub-Karagan swell on the west and the Karatau swell on the east. The Permian-Triassic sequence crops out in the cores of these swells. Younger beds of the sedimentary cover dip 18-20° on the flanks. The Bekebashkuduk swell forms the southern part of the system of uplifts. It is divided from the Tyub-Karagan and Karatau swells by the narrow Chakyrgan trough. Folded Permian-Triassic rocks occur at depths of 400-500 m near the crest of the Bekebashkuduk swell. To the southeast, the Mangyshlak system of uplifts splits into several subparallel swells divided by narrow depressions, forming a zone of virgation (Muromtsev, 1968b). The most western of these swells, the Tumgachi swell, is the largest. It cuts the Bekebashkuduk swell and the Chakyrgan trough and continues to the South Mangyshlak trough (Zhivoderov, 1967).

The South Mangyshlak trough itself consists of two large depressions separated by the Karagii saddle. The western depression is known as the Segendyk depression; only its eastern part lies onshore. The Zhazgurly depression is the largest part of the South Mangyshlak trough. The northern flank of the Zhazgurly depression is steeper (3-3.5° at the base of the Cretaceous section) than the southern flank (1-1.5°). The thickness of the platform cover in the depression reaches 5100 m; the base of the Hauterivian occurs at a depth of 2800 m (see Fig. 40).

The Zhetybay (or Zhetybay-Uzen) step forms part of the northern flank of the South Mangyshlak trough. On the south, the step is bordered by a large, steep flexure that evidently reflects a fault in the Triassic sequence (Chakabayev et al., 1976). On the north, the step is separated from the Bekebashkuduk swell by another fault (see Fig. 41). The step is complicated by some local uplifts, the most prominent of which are the Zhetybay and Uzen folds. These uplifts form two anticlinal lines, with the Uzen fold line to the north and the Zhetybay fold line to the south. The step is slightly inclined to the south and west. These and other details of the step's structure are shown in Fig. 41.

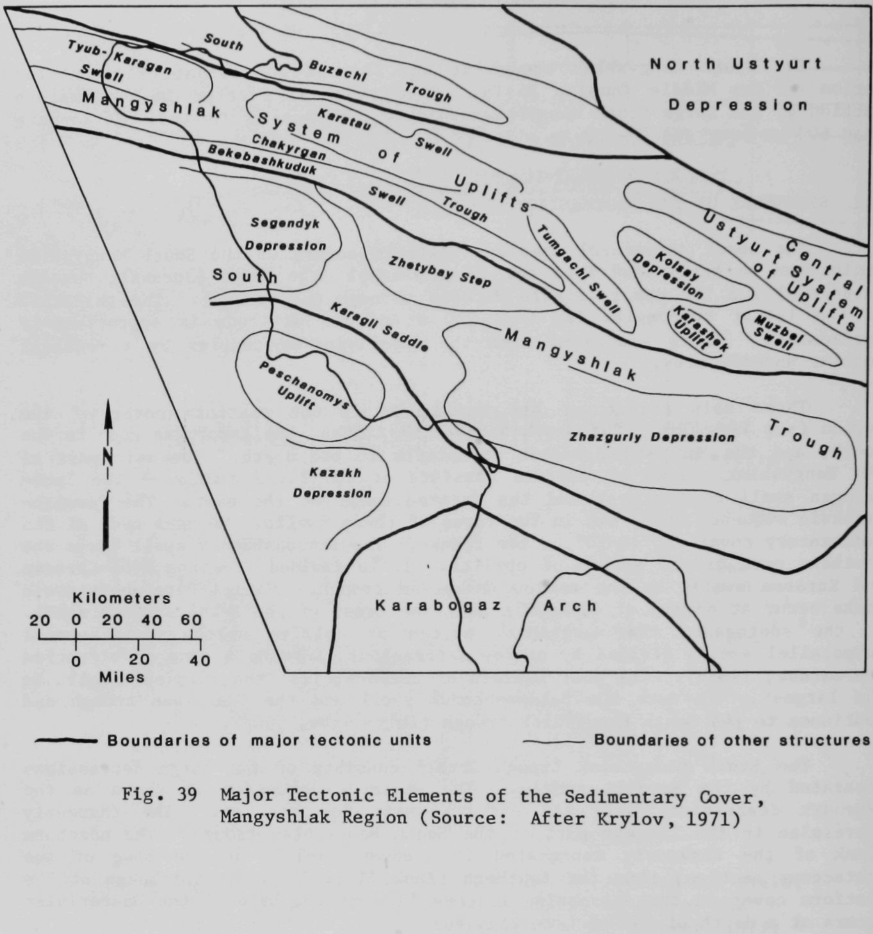


Fig. 39 Major Tectonic Elements of the Sedimentary Cover, Mangyshlak Region (Source: After Krylov, 1971)

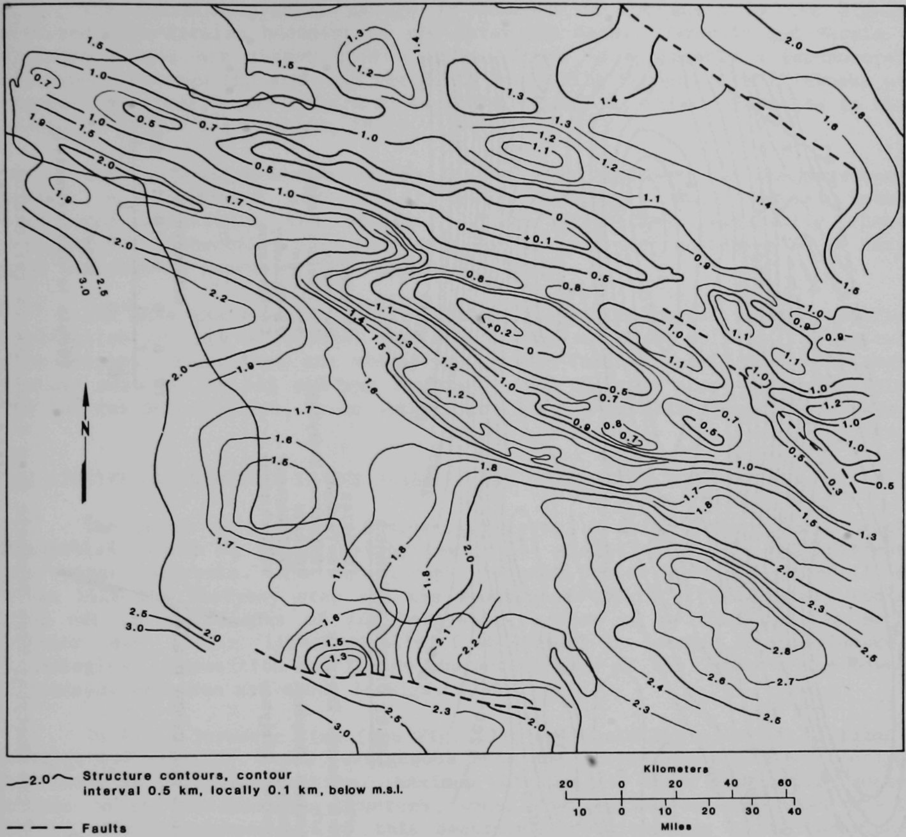


Fig. 40 Structural Map for the Base of the Hauterivian (reflecting horizon III-g), South Mangyshlak Region (Source: Mainly after Sorotskaya, 1968)

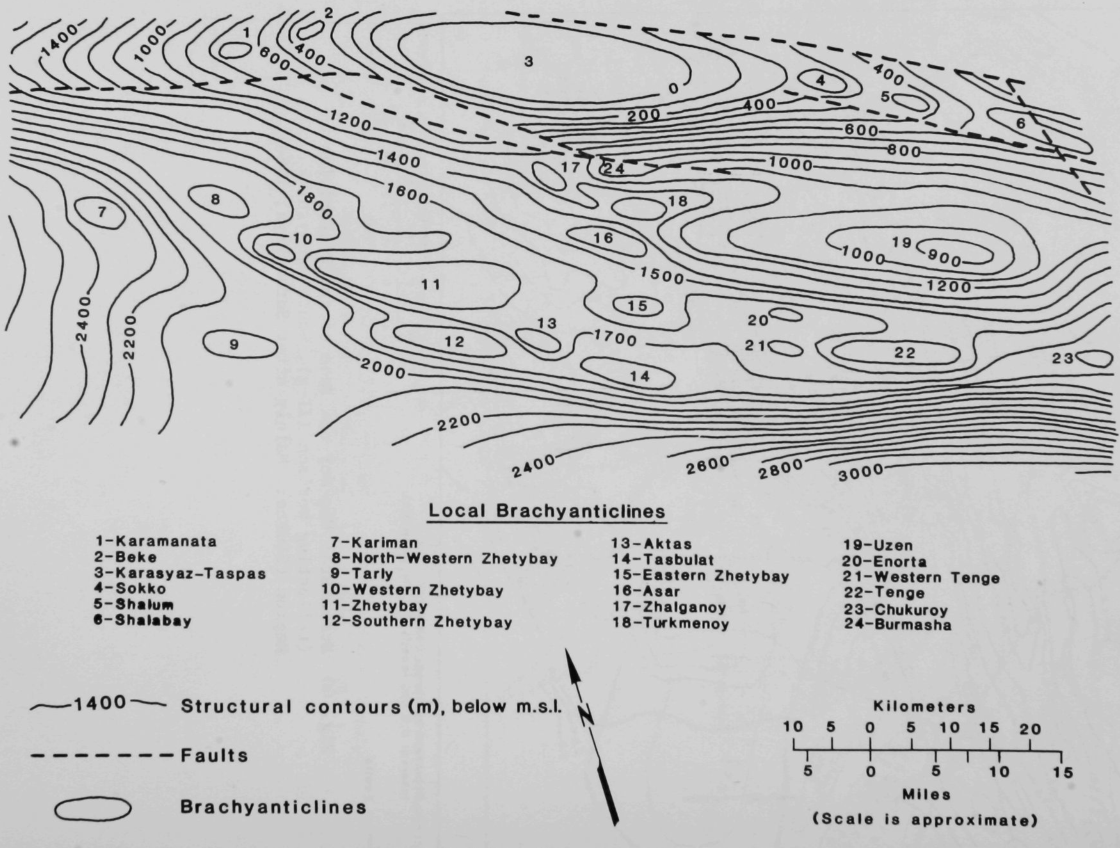


Fig. 41 Sructural Map of the Zhetybay-Uzen Tectonic Step (contours on reflecting horizon III (Oxfordian limestones) (Source: After Yuferov et al., 1978)

The South Mangyshlak trough is bounded on the south by the highly elevated, pre-Permian basement of the Karabogaz arch. Jurassic and Permian-Triassic strata are absent on the arch. There is apparently a fundamental difference between the arch and the South Mangyshlak trough. The thickness of the earth's crust beneath the arch is 26,000-28,000 m, and it increases in the trough to 49,000 m (Zakhidov, 1971).

The large Peschanomys uplift lies to the northwest of the Karabogaz arch. A significant part of it occurs offshore, where several local structures complicate the uplift. These structures, especially those designated Rakushechnoye-more and South Peschanoye, are considered to be very good exploration prospects (Nikolayeva, 1974).

The main characteristic of the South Mangyshlak region is the steplike inclination of its structural surfaces, from marginal uplifts to central depressions. Such steps are widespread in the Turanian plate and there they contain most of the oil and gas reserves. The Zhetybay step, which controls oil and gas accumulation, is an outstanding example of this type of structure.

7.2 FACIES DISTRIBUTION IN THE JURASSIC AND LOWER CRETACEOUS SECTION

The lower part of the sedimentary cover in axial areas of the South Mangyshlak trough is penetrated by few wells, and stratigraphic subdivisions are rather uncertain. The stratigraphy is much better known in well-drilled areas like the Zhetybay step and the Peschanomys uplift. Sedimentary rocks crop out on the flanks of the Mangyshlak system of uplifts but are much thinner and differ lithologically from those in areas of subsidence. Lithological composition and facies characteristics of the Jurassic and Lower Cretaceous sections are shown in Figs. 42-47.

In Early Jurassic time (see Fig. 42), sedimentation occurred in lakes, swamps, and rivers. These terrigenous beds are coarser in the lower section and finer in the upper section. Maximum thickness of these sedimentary rocks occurs on the Peschanomys structure, where the section is more than 300 m thick. The lowermost part of this sequence is believed to be of Rhaetian-Liassic age (Kononov and Chakabayev, 1970). Mostly coarse-grained beds occupy the axial part of the trough and the north flank of the Karabogaz arch. The rocks are characterized by significant lithological variability and by abrupt, lateral pinch-outs.

The thick Middle Jurassic sequence (see Fig. 43) contains the main oil reserves of the region. In Aalenian time, sedimentary conditions were quite similar to those of the Early Jurassic. During the Bajocian and Bathonian stages, more fine-grained sediments were deposited. During this time, terrestrial sedimentation predominated, but marine intercalations do appear in the upper Bajocian and become more common in the Bathonian sequence, especially in the axial zone of the South Mangyshlak trough. The sandstone content decreases from the uplifts to the trough (Benenson et al., 1967). Sandstones and siltstones are poorly sorted, and the grains are irregularly rounded. Kaolinite and chlorite cements predominate, indicating a humid climate (Aktanova, 1968). There are some layers of highly bituminous shales enriched by volcanic glass. Significant lithological variations are favorable for formation of stratigraphic traps, especially along the borders of the

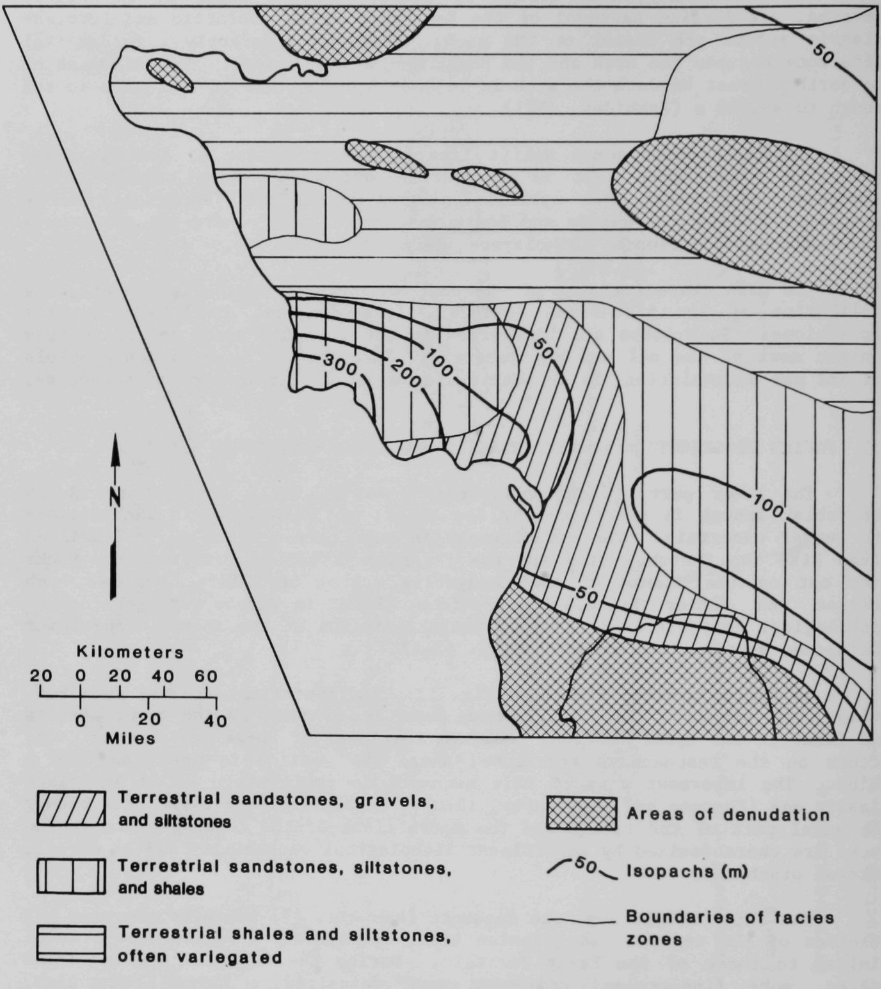


Fig. 42 Facies of the Lower Jurassic Sedimentary Sequence (Source: After Azizov et al., 1977)

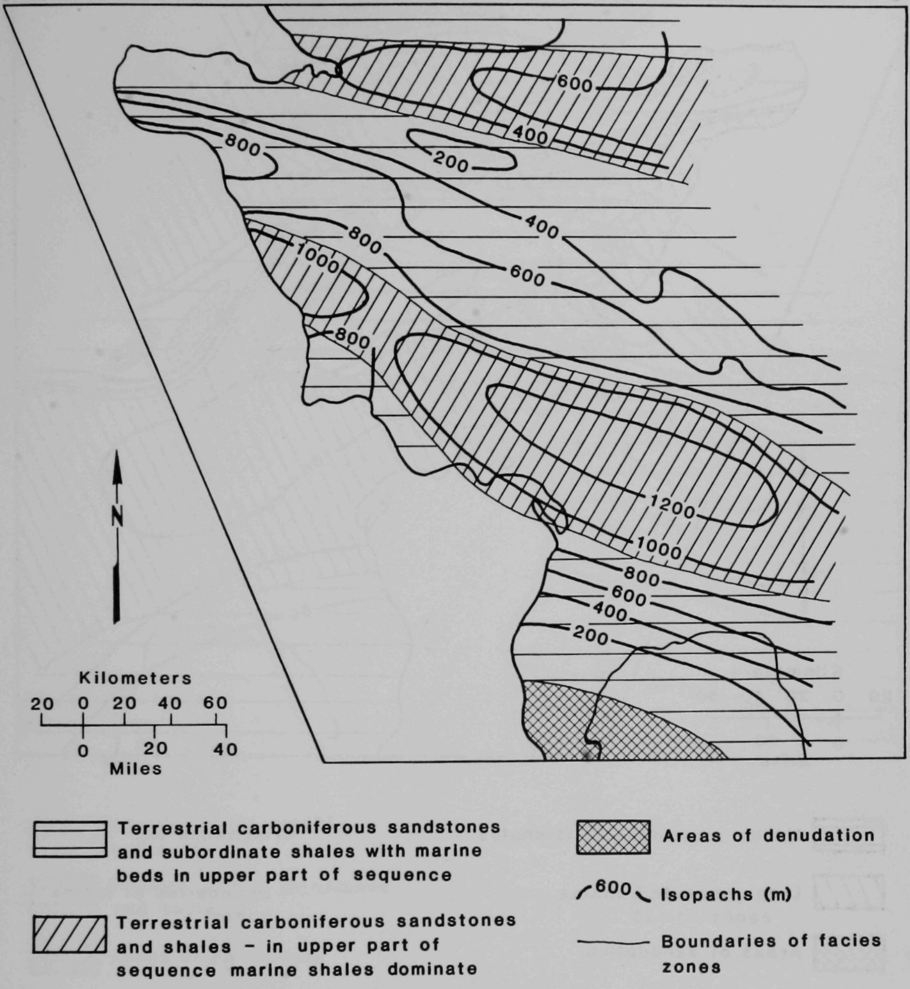


Fig. 43 Facies of the Middle Jurassic Sedimentary Sequence
(Source: Compiled from Muromtsev, 1968a)

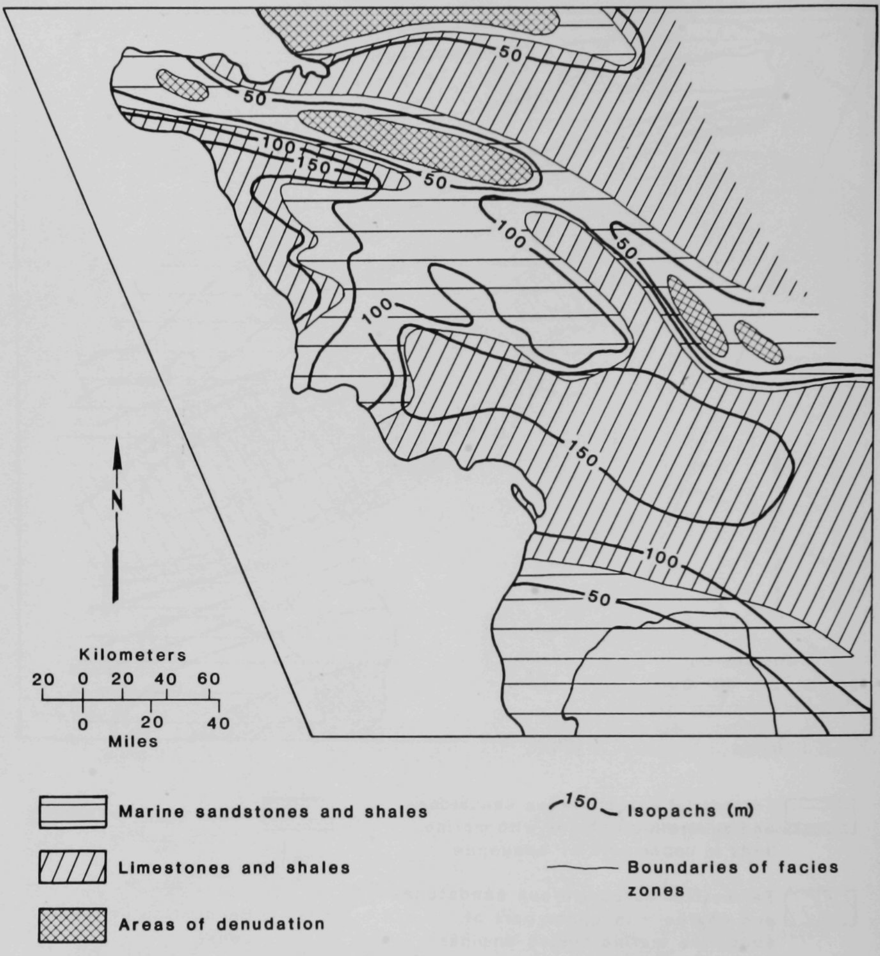


Fig. 44 Facies of the Callovian Sedimentary Sequence (Source: After Muromtsev, 1968a)

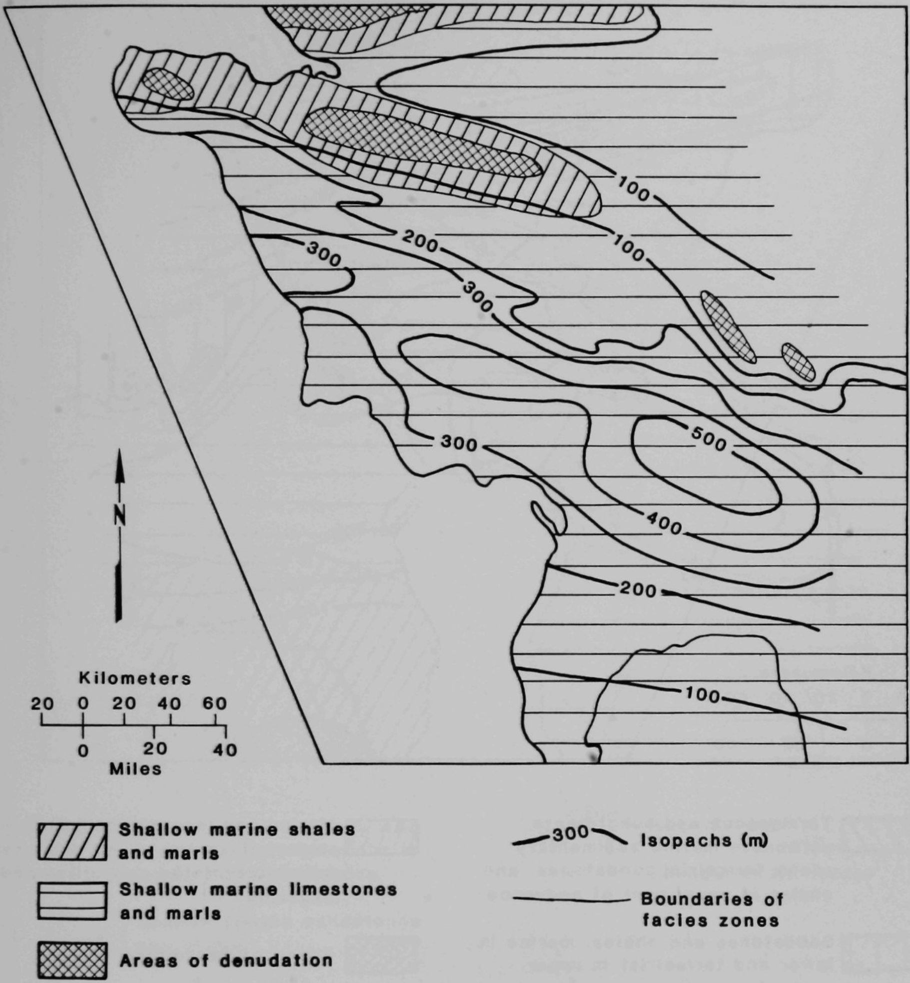


Fig. 45 Facies of the Kimmeridgian-Oxfordian Sedimentary Sequence (Source: After Muromtsev, 1968a)

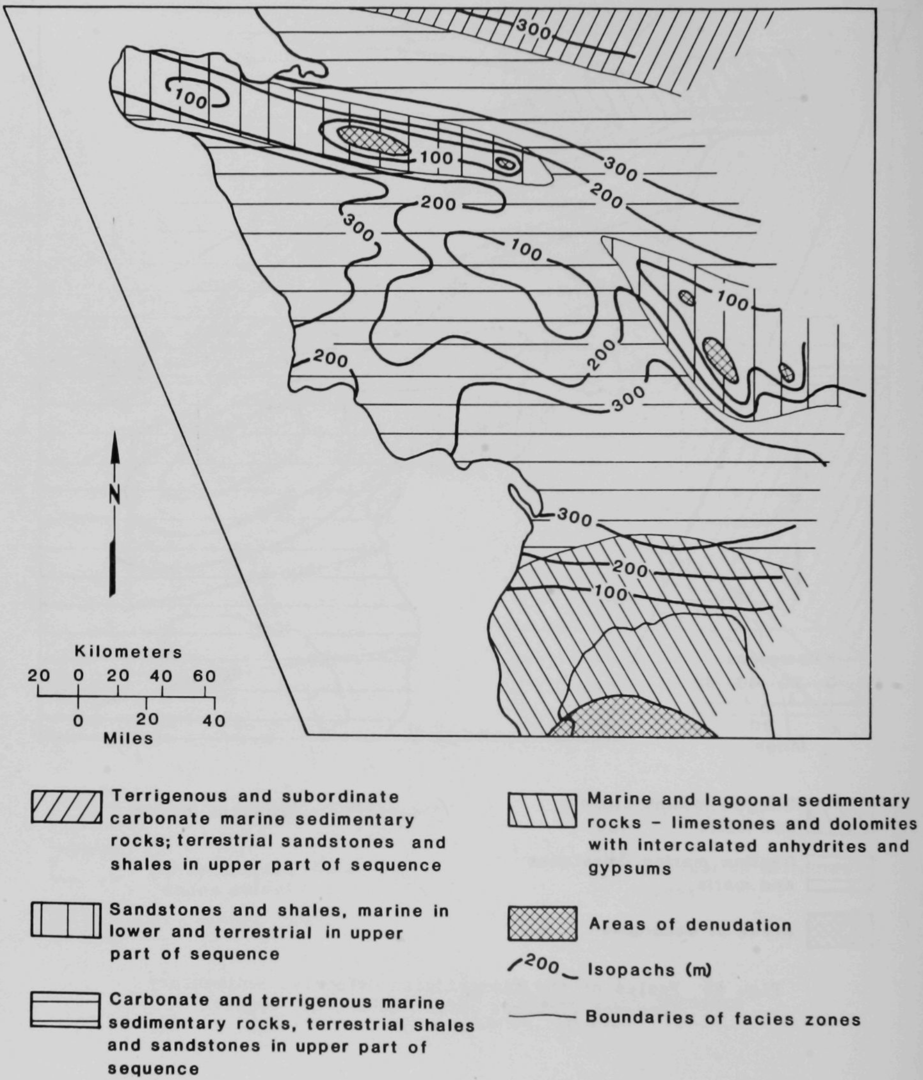


Fig. 46 Facies of the Neocomian Sedimentary Sequence (Source: Compiled from Muromtsev, 1968a)

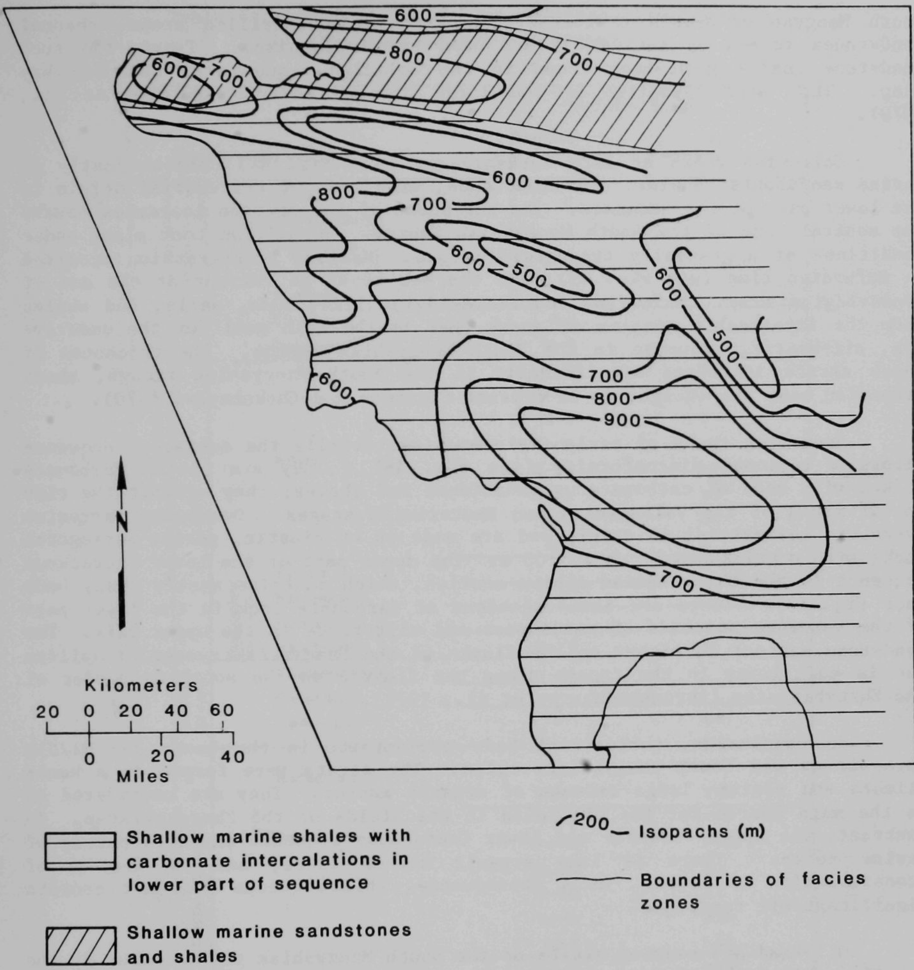


Fig. 47 Facies of the Aptian-Albian Sedimentary Sequence (Source: Compiled from Muromtsev, 1968a)

South Mangyshlak trough (Muromtsev, 1974). In well-drilled areas, channel sandstones formed by ancient rivers have been recognized. Twenty-two such sandstone bodies have been found in the Bajocian sequence of the Zhetybay step. They were deposited by the large Uzen paleoriver (Yuferov et al., 1978).

Callovian rocks of late Jurassic age (see Fig. 44) consist mostly of marine sandstones, shales, and limestones, with beds of terrestrial origin in the lower part of the sequence. The thickness of the section increases toward the central zone of the South Mangyshlak trough. Deposition took place under conditions of a gradually transgressing sea. Maximum transgression occurred in Oxfordian time (see Fig. 45), and the sea began to retreat at the end of Kimmeridgian time. Oxfordian and Kimmeridgian limestones, marls, and shales form the impermeable complex of rocks that is the main seal for the underlying, oil-bearing sequence in the South Mangyshlak region. The thickness of these strata increases significantly in the South Mangyshlak trough, where Tithonian beds are thought to be present (Kononov and Chakabayev, 1970).

Neocomian rocks of early Cretaceous age overlie the subjacent sequence across a regional disconformity (see Fig. 46). They are mostly carbonate rocks, with beds of carbonaceous sandstones and shales; they exhibit the rich fossil fauna of the Valanginian and Hauterivian stages. Overlying Barremian rocks are terrestrial in origin and are made up of clastic, partly variegated rocks with a thickness of up to 100 m. The upper part of the Lower Cretaceous sequence is the thick Aptian-Albian section, which contains mostly shaly beds (see Fig. 47). There are intercalations of carbonate rock in the lower part of the sequence and beds of sandstones and siltstones in the upper part. The sandstone content is higher on the flanks of the Mangyshlak system of uplifts but is much lower in the trough along the flexure on the southern border of the Zhetybay step (Akramkhodzhayev et al., 1971).

In conclusion, terrestrial beds predominate in the Lower and Middle Jurassic of the South Mangyshlak region. The strata were formed in a humid climate and contain large amounts of organic matter. They are considered to be the main source for the oil found in the fields of the Zhetybay step. In contrast, the Upper Jurassic and Lower Cretaceous sequence consists mainly of marine rocks. There is less organic matter there, and the degree of transformation is lower. As a consequence, this sequence does not contain significant oil reserves.

Oil- and gas-bearing strata of the South Mangyshlak region occur in the stratigraphic interval from the Turonian Stage of the Upper Cretaceous to the Triassic (see Table 4). These strata are made up of sandstones and siltstones. Main oil-bearing horizons are referred to by a regional nomenclature that goes from Yu-I to Yu-XIII in the Jurassic part of the sequence. The rocks are mostly graywackes and graywacke-arkoses. They usually contain poorly rounded grains, are poorly to moderately sorted, and have kaolinite-chlorite cement, all of which point to the terrestrial origin of the sediments and the humid conditions of their deposition. The amount of clayey material ranges widely from several percent to 40-50%; it is usually rather high. Reservoir properties of the sandstones and siltstones change quickly, both laterally and vertically. The best reservoirs are linear bodies deposited by ancient rivers. They are widespread in the Zhetybay Step and, presumably, in

Table 4 Stratigraphic Column and Productive Strata of the South Mangyshlak Region

Stratigraphic Column				Productive Strata: Regional Nomenclature	Productive Strata: Uzen Nomenclature
Cretaceous	Upper		Danian		
			Maestrichtian		
			Campanian		
			Santonian		
			Coniacian		
			Turonian	M-I	I
			Cenomanian	M-II	II
	Lower		Albian	M-III	III
				M-IV	IV
				M-V	V
				M-VI	VI
				M-VII	VII
				M-VIII	VIII
				M-IX	IX
				M-X	X
			Aptian		
		Neocomian	Barremian	M-XI	XI
			Hauterivian		
			Valanginian	M-XII	XII
Jurassic	Upper (Malm)		Kimmeridgian		
			Oxfordian		
			Callovian	Yu-I	XIII
				Yu-II	XIV
	Middle (Dogger)		Bathonian	Yu-III	XV
				Yu-IV	XVI
			Bajocian	Yu-V	XVII
				Yu-VI	XVIII
				Yu-VII	XIX
				Yu-VIII	XX
				Yu-IX	XXI
				Yu-X	XXII
			Aalenian	Yu-XI	XXIII
				Yu-XII	XXIV
	Lower (Liassic)			Yu-XIII	XXV
Triassic				Not Identified	

the central part of the South Mangyshlak trough. Reservoir properties improve in going from subsided to uplifted structures (Khanin, 1973).

The Cretaceous sequence contains 12 reservoir strata, which are referred to by a regional nomenclature (M-I through M-XII). Reservoir properties of these strata are better than those for the Jurassic strata and show less variation laterally. Although oil flows have been obtained from Triassic beds in several fields, there are not enough data for correlation of productive beds (Yuferov et al., 1977).

7.3 OIL AND GAS FIELDS

Oil and gas pools in fields of the South Mangyshlak region occur mostly in sedimentary rocks of the Lower Jurassic through the Callovian Stage of the Upper Jurassic. Thirteen oil and gas fields of varying commercial importance have been discovered in the region. The most prominent of them is the supergiant Uzen field, which will be described in detail in Sec. 8.

The next most important field, which is considered a giant, is the Zhetybay oil and gas field (see Fig. 48). Recoverable reserves were estimated to be as high as 175×10^6 m^3 of oil and 31×10^9 m^3 of gas by Halbouty et al. (1970). The field was discovered in 1961 (the same year as the Uzen field), but exploitation did not begin until the middle 1960s. The maximum output of oil evidently was achieved in 1975-1976, when it reached about 4×10^6 t/yr (Dienes and Shabad, 1979). The field is associated with an anticlinal fold more than 20 km long. The southern flank of this structure is slightly steeper (3°) than the northern flank (less than 2°). Closure of the structure on the Callovian is 90 m. The anticline began to form during the Early Jurassic and continued to grow until the Quaternary (Chakabayev et al., 1977b). It is also assumed that oil accumulated in the pools over a long period of time.

Twenty-three of the oil and gas pools of the Zhetybay field are concentrated in that part of the sequence ranging from the Callovian to the Aalenian, although a small pool also is found in the Lower Jurassic. The main gas reserves are associated with upper Callovian and Bathonian strata. The main oil reserves are concentrated in the Aalenian and the lower part of the Bajocian (see Fig. 48). Some of the oil-bearing strata contain gas caps. There are large variations in the sizes of pools, in the positions of the oil-water contacts, and in the yields of the wells. The most constant and largest yields are obtained by exploiting the thick, massive sandstones of strata Yu-XII and Yu-XIII (Aronson and Makhonin, 1973). Major pools have their own oil-water or gas-water contacts, which sharply differentiates them from those of the Uzen field. There the major pools have a common oil-water contact. This shows that there has been significantly less redistribution of pools within the Zhetybay field as compared to the Uzen field (Yuferov et al., 1973). The absence of gas pools in the overlying Lower Cretaceous sequence of the Zhetybay field, but which are present in the Uzen field, supports this conclusion. Oil-water contacts of the Zhetybay field lie between 1670 m and 2270 m bsl; the upper gas-water contact of stratum Yu-I is at 1600 m bsl. Reservoir pressures increase downward (from 185 kgf/cm^2 to 250 kgf/cm^2), and reservoir temperatures vary from 80°C to 100°C (Kortsenshtein, 1972).

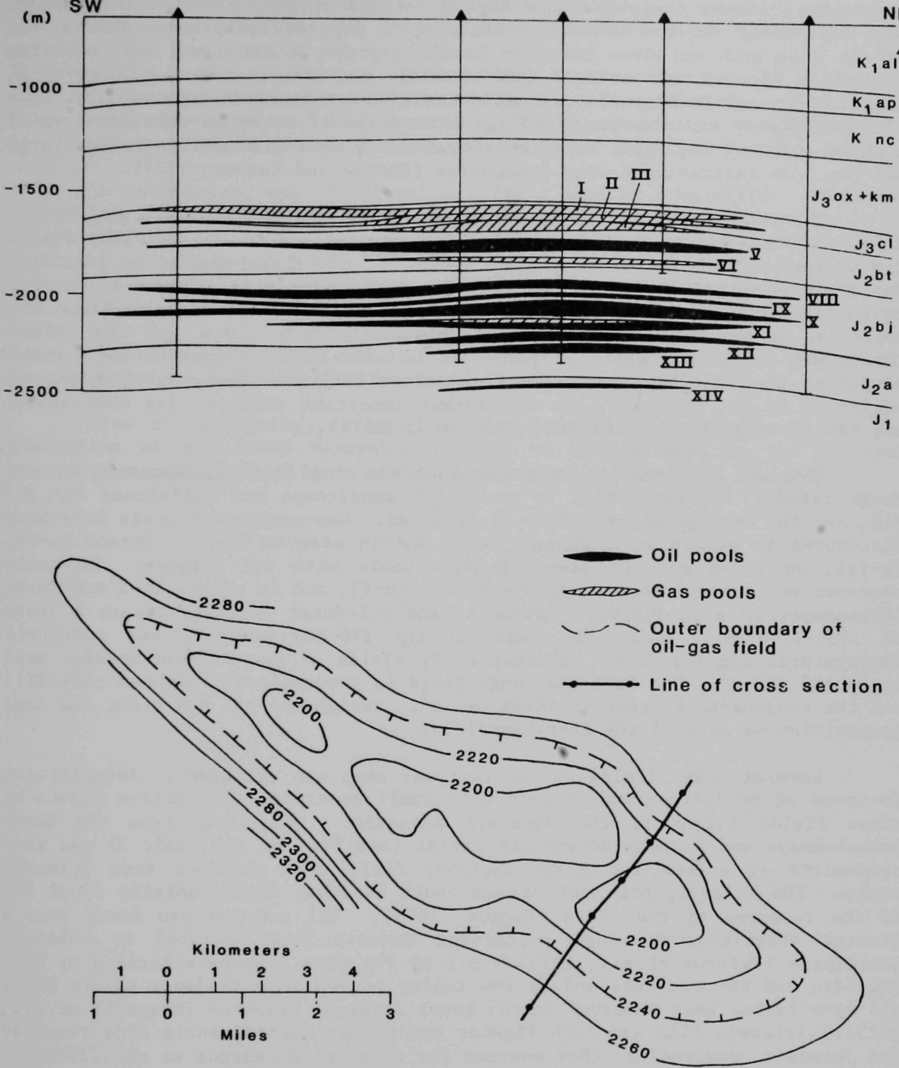


Fig. 48 Cross Section and Contour Map for the Zhetybay Oil-Gas Field, South Mangyshlak Region (contours [in m] on top of the producing stratum XII) (Source: After Dikenshtein et al., 1977)

Oils of the Zhetybay field have densities of 0.83 g/cm^3 to 0.88 g/cm^3, with a tendency for the density to decrease in progressively lower strata. As is the case with oil from the Uzen field, Zhetybay's oil has a high paraffin (up to 26.5%) and tar content (up to 18%), and a low sulfur content (Ulm, 1968). In terms of composition, methane-series hydrocarbons predominate. Gas of the Zhetybay field contains a high percentage of heavy gaseous homologs of methane and 2-6% nitrogen. The concentration of hydrogen sulfide is not large but has been increasing during production (Karpov and Raaben, 1978).

The third oil field of importance in the South Mangyshlak region is the Tenge field, but its reserves are far less than those of the Zhetybay field. Gas reserves of the Tenge field are 25-30 x 10^9 m^3 (Chakabayev et al., 1977b). The field occurs to the south of the Uzen field (see Figs. 32 and 41) and is on an elongated, rather narrow anticline about 20 km long and 3 km wide. The amplitude of the fold on the Callovian stratum Yu-I is 120 m, and dips on the flanks are 5-6°. The southern flank of the anticline impinges on the flexure bordering the Zhetybay step. This inherited anticline began to form at the beginning of the Jurassic, but the latest important phase of its development was in pre-Neogene time (Chakabayev et al., 1967b).

Thirteen producing strata are found in the Jurassic sequence of the Tenge field. The porosities of reservoir sandstones and siltstones are 15-21%, and the average permeability is 30-90 md. Gas-condensate pools have been discovered in strata Yu-I through Yu-V, and in stratum Yu-XI. Strata Yu-VI, Yu-VII, and Yu-X contain gas-condensate pools with oil fringes. The main reserves are concentrated in strata Yu-II, Yu-VI, and in strata Yu-X and Yu-XI (Chakabayev et al., 1967b). Gas-water and oil-water contacts lie at a depth of 1535-2140 m. Reservoir pressures are 170-240 kgf/cm^2, and reservoir temperatures are 87-105°C. Initial daily yields of gas from an average well reach 150,000 m^3. Gas from the Tenge field is predominantly methane (86-93%), and the condensate content is 48-64 cm^3/m^3. Peripheral oil has about the same composition as oils of the Zhetybay field.

Several other fields on the Zhetybay step are relatively insignificant in terms of production and contain only small reserves. Productive strata of these fields belong to the Jurassic sequence. Oil flows from the North Rakushecnoye and Rakushechnoye-more fields (see Fig. 32 and Table 3) and gas-condensate flow from the South Zhetybay field were obtained from Triassic rocks. The Triassic oil pool of the South Zhetybay field contains about 70% of the reserves of the field (Popkov, 1979). Oil and gas are found over a greater stratigraphic range proceeding downdip from uplifted to subsided structures (Yuferov et al., 1973). All of the oils are characterized by high paraffin and tar contents and by low sulfur content. A tendency toward lower oil density has been observed in the Lower Jurassic sequence (Kraychik et al., 1973). Triassic oils are much lighter and differ significantly from those of the Jurassic, suggesting other sources for these oils (Kordus et al., 1974).

Oil and gas flows also were recovered from Upper Jurassic (stratum Yu-I) and Aptian rocks on the west pericline of the Bekebashkuduk swell, on the Dunga and Espelisay structures. These pools are small but indicate the possibility of future discoveries in the Lower Cretaceous sequence further to the west in the offshore area. These structures have a different origin compared with those of the Zhetybay step. They formed in Neogene time, whereas the anticlines on the Zhetybay step began to form at the beginning of the

Jurassic (Gavrilov et al., 1974). The oils are characterized by relatively low density (0.811-0.819), due to a higher content of light fractions. The paraffin and tar content is significantly lower than in the oils of the Zhetybay step. The temperature of congealing is also less (+13°C). Although some believe that these oils indicate a separate oil-producing complex in the Lower Cretaceous sequence (Gavrilov et al., 1974), these oils usually are considered to have migrated from the Jurassic sequence (Kraychik et al., 1973).

In conclusion, one additional oil field must be considered. It is the Tyubedzhik field on the Tyub-Karagan swell. This field contains pools of heavy, degassed oil in Albian and Neocomian rocks; the dimensions of the structure are 10 km x 20 km. Although the oil pools are rather large, they are not of commercial significance. Oil-bearing strata lie at a depth of 300-400 m. Since the oil contains almost no light fractions, its density is high (0.945 g/cm^3). Its kinematic viscosity at 50°C exceeds 750 cs. It is tarry, but the content of paraffin and sulfur is small. Exploitation of these pools is considered unprofitable (Trifonov and Yevstifeyev, 1968).

From the foregoing, it is clear that virtually all of the oil and gas production of the South Mangyshlak region is concentrated on the Zhetybay step, and more specifically in the large Zhetybay and Uzen oil fields.

8 THE UZEN FIELD

The Uzen field is the largest in the Middle Caspian Basin and one of the largest in the USSR. It was discovered in 1961 and production began in 1965.

8.1 CHARACTERISTICS OF THE TRAP

The geological section of the Uzen field consists of rocks of Triassic through Tertiary age. Neogene, Paleogene, and some Upper Cretaceous rocks are exposed at the surface. The Uzen field is associated with a large anticline that is about 45 km long and 9 km wide (see Fig. 49). This fold began to form at the beginning of Jurassic time and developed slowly up to the Quaternary (Gribkov and Lazarev, 1968). Major deformation took place at two times -- pre-Neocomian and pre-middle Miocene (Yesenov and Makhambetov, 1965). The fold is significantly asymmetrical, with the crest of the fold displaced to the east. The northern flank dips at 1.5-2°, whereas the southern flank is steeper, with dip angles reaching 6-8°. The western pericline of the fold is complicated by three subsidiary closures -- the Khumuryn, Parsymuryn, and Karamandybas. The last of these is separated from the others by a small fault and is often considered a separate structure. Some other small faults are recognized based primarily on well log and reservoir data (Sagitov et al., 1975). Yuferov et al. (1975b) conclude that the distribution of small oil pools in the lower part of the Jurassic sequence also is controlled by low amplitude faults (see Fig. 50).

8.2 RESERVOIR ROCKS

Twenty-five reservoir strata are distinguished in the Cretaceous and Jurassic sequence of the Uzen field. The reservoir rocks are mainly polymictic sandstones and siltstones with a high content of clayey material; they are separated from each other by impermeable shaly and carbonaceous-shaly rocks. The first 12 reservoir strata occur in the Cretaceous sequence and form the upper gas-bearing complex. The other 13 lie in the Jurassic part of the sequence and form the lower oil-bearing complex. This report uses the older nomenclature for the strata of the Uzen field because of its prevalence in the Russian literature.

Strata I-XII (see Table 4) occur at depths of 190-900 m. They consist of friable sandstones and siltstones with porosities of 26-34% and permeabilities of 200-600 md. The number of sandy beds varies from one (stratum V) to four or five (strata III-VIII). The thicknesses of the strata range from 10 m to 40-50 m.

Stratum XIII (see Fig. 51) in the Callovian sequence, and stratum XIV contain the main oil reserves of the field. Stratum XIII is characterized by rapid variability in reservoir properties. From 1 to 12 reservoir horizons are found in the five beds of stratum XIII. Its average thickness is about 35 m, and the total average effective thickness of the reservoir layers is 11.6 m (Bykov et al., 1967). A typical well drilled into stratum XIII will intersect an average of five to six sandstone layers; about 34% of the entire

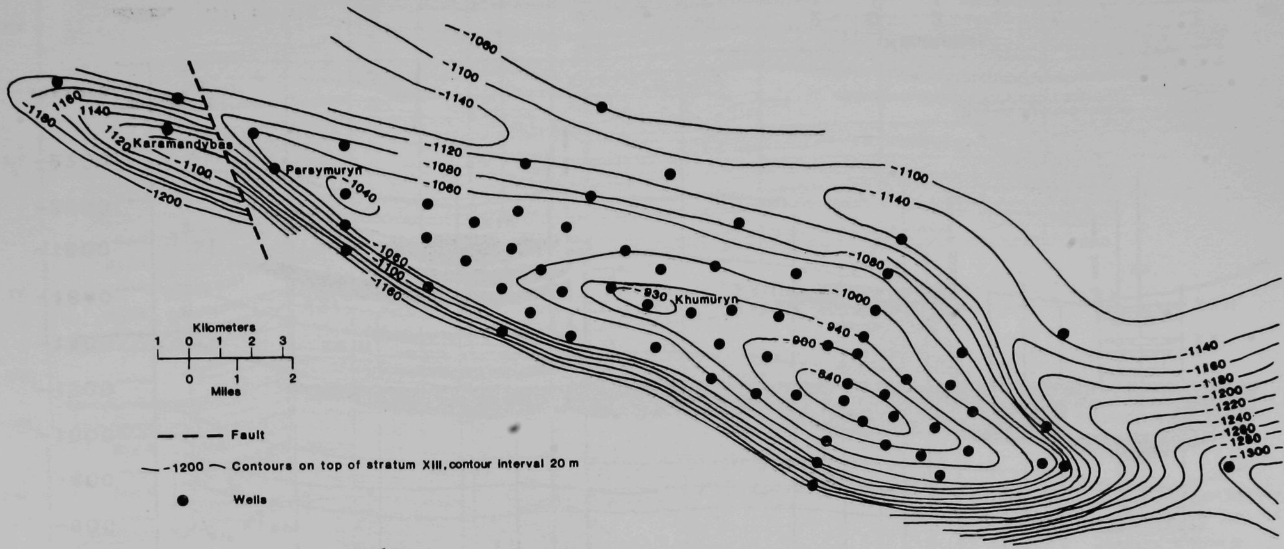


Fig. 49 Structural Map of the Uzen Field (contours on top of producing stratum XIII) (Source: After Makhambetov, 1968)

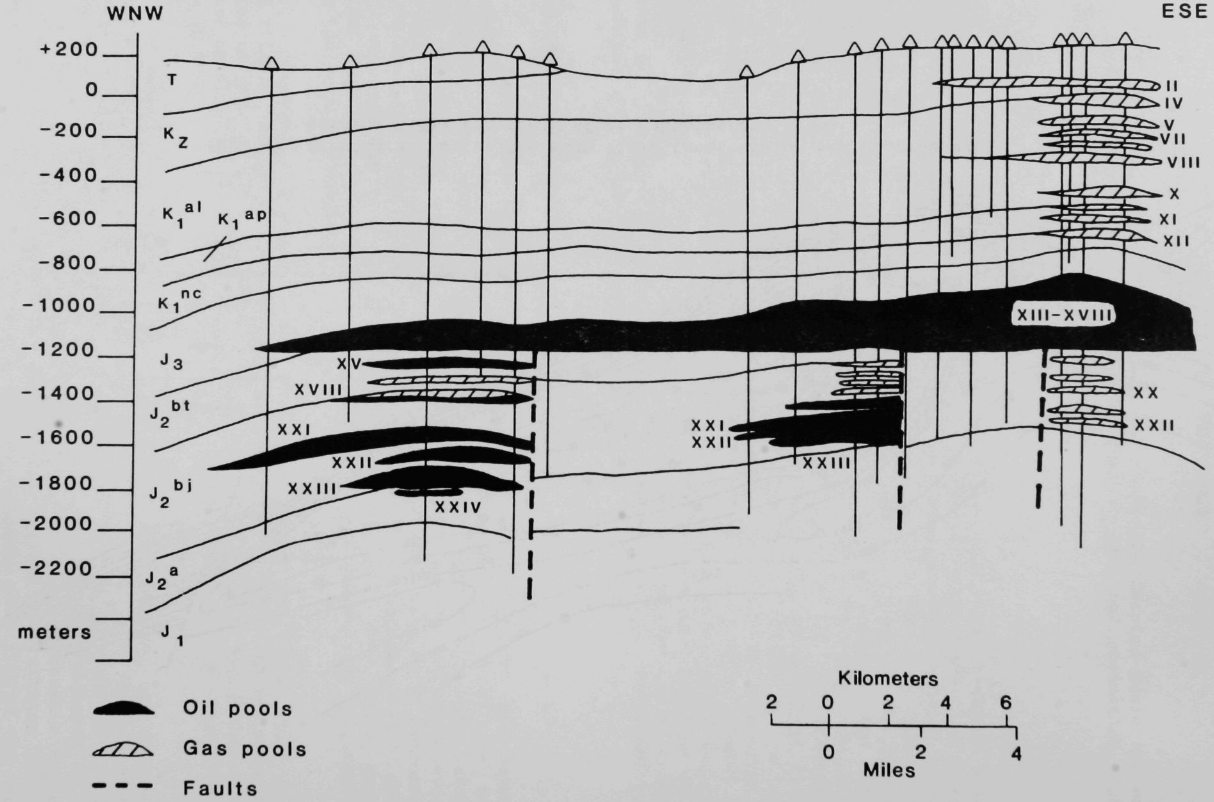


Fig. 50 Cross Section along the Long Axis of the Uzen Field (Source: After Aleksin et al., 1969)

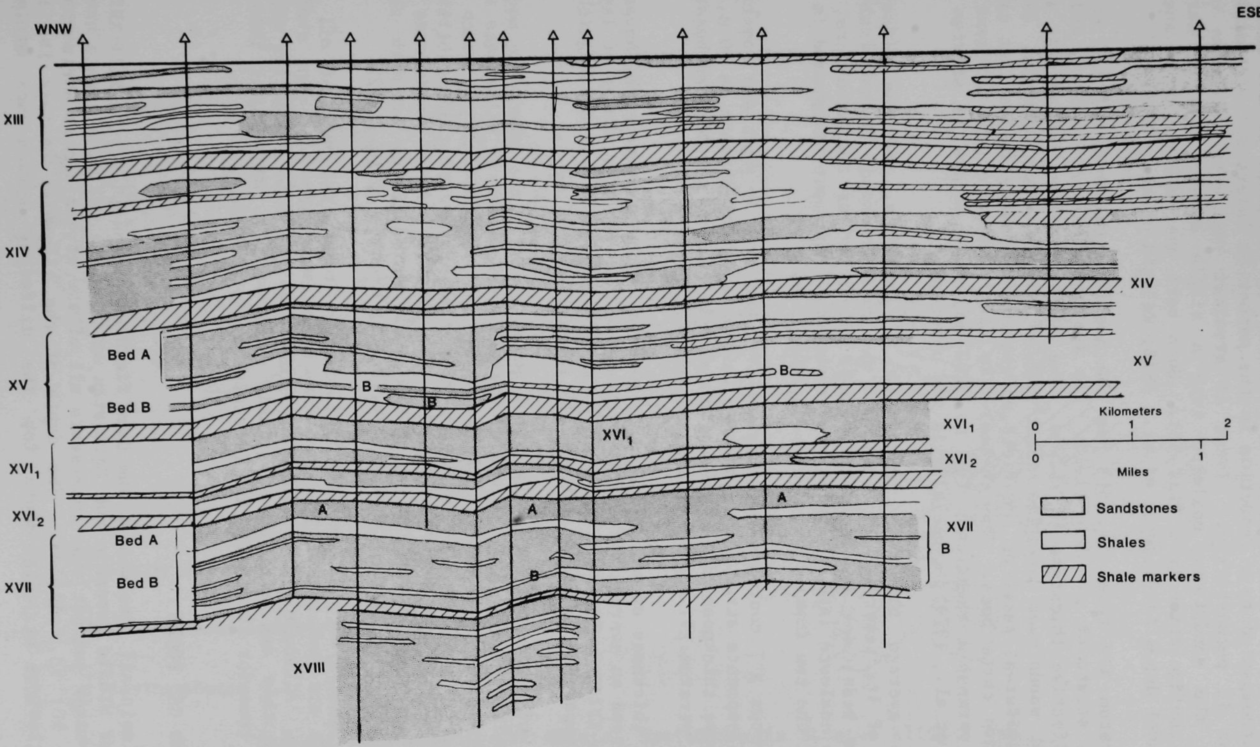


Fig. 51 Cross Section through Productive Strata of the Uzen Field (Source: After Bykov et al., 1968)

section consists of sandstones. An increase in thickness of the reservoir rocks is accompanied by a reduction in the number of layers and a significant improvement in permeability. Zones of greatest reservoir thickness occur where all the sandstones coalesce into a single massive bed of narrow, elongated configuration (see Fig. 52). Such beds are believed to be ancient river channel deposits (Yuferov et al., 1978; Kalugin et al., 1976).

Stratum XIV (see Fig. 51) has the greatest thickness of all of the productive strata of the Uzen field. Its average thickness is 60 m, and its average effective thickness is 31.5 m. The average number of layers is about eight, and sandstones comprise about 55% of the sequence (Khanin, 1973). Wells in different parts of the field penetrate 7-12 sandy layers that can be grouped into three beds. The channel-like distribution of the thickest and the most permeable sandstones (up to 1200 md) also occurs in stratum XIV (Ivanchuk et al., 1979), especially in its upper part.

The average thickness of stratum XV is 45 m, and the effective thickness of its reservoir rocks is 17.8 m. Up to 10 sandy layers, combined into three beds, are distinguished. Near the crest of the structure, the three beds coalesce into a single thick reservoir. The most widespread is the upper bed; the two lower beds cover much less area.

Stratum XVI contains two beds -- XVI_1 and XVI_2 -- that are sometimes considered separate strata. The average thickness of the stratum is 30 m, and the effective thickness of the reservoir rocks is 21.1 m. On the southeastern pericline, stratum XVI coalesces with superjacent stratum XV.

The thickness of stratum XVII is 40-66 m, with an average thickness of about 50 m and an average effective thickness of 29.4 m. The number of layers in stratum XVIII reaches 11. Two or three reservoir beds are distinguished, which are separated by clayey layers with thicknesses of 1-9 m.

All of the reservoir rocks of strata XIII-XVIII are poorly to moderately sorted; they are fine- to medium-grained sandstones and siltstones with clayey and calcareous cement. The content of clayey material can reach 40% and more. Reservoir rocks are characterized by sharply varying permeabilities that range from a few to 1000-1200 md. The porosity of the sandstones and siltstones does not correlate well with their permeability or with their content of clayey material. Porosity is 18-23%; usually it is 21-22%.

The underlying strata (XIX-XXV) contain minor reserves of oil and gas. They are penetrated by very few wells and have not been studied extensively. Although these strata are similar to the main productive strata XIII-XVIII, they are even more variable in reservoir properties. This is especially true for strata XIX-XXI (Aleksin et al., 1969).

8.3 OIL AND GAS POOLS

The main oil reserves of the Uzen field are found in strata XIII-XVIII, which are of Middle Jurassic and Callovian age. Pools of these strata have a common oil-water contact that intersects all of the strata almost horizontally (see Figs. 50, 53, and 54). The depth of the oil-water contact is 1124-1150 m; variations in this depth for the different strata are minimal.

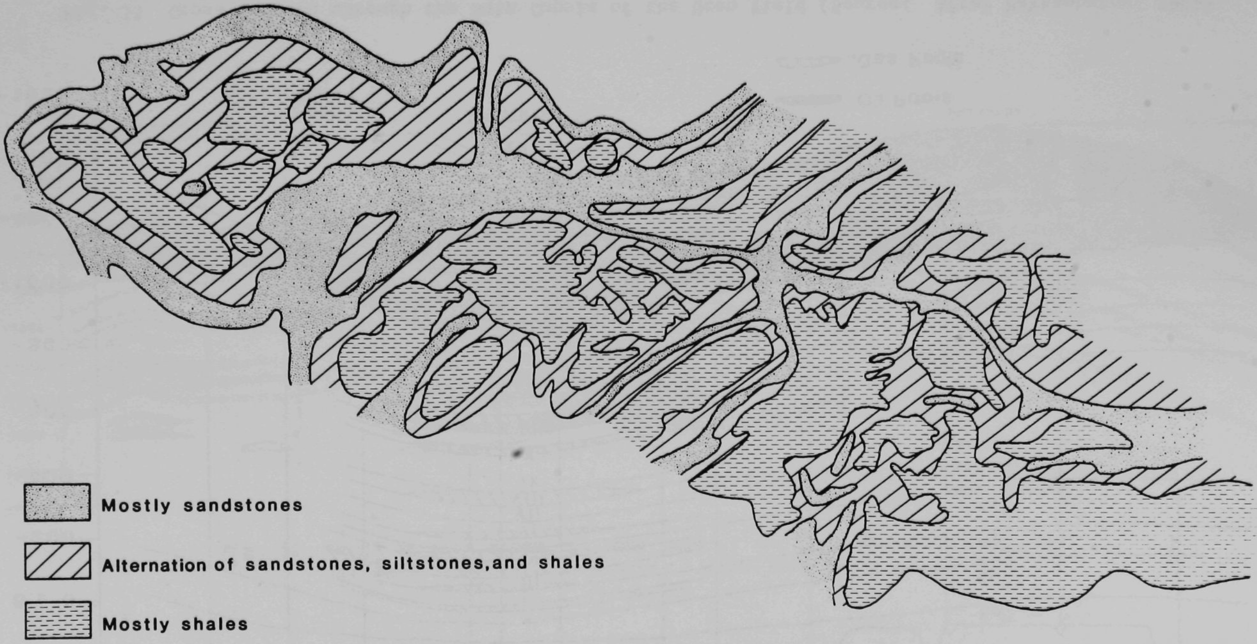


Fig. 52 Distribution of Channel Sandstones in Stratum XIII of the Uzen Oil Field (Source: After Kalugin et al., 1976)

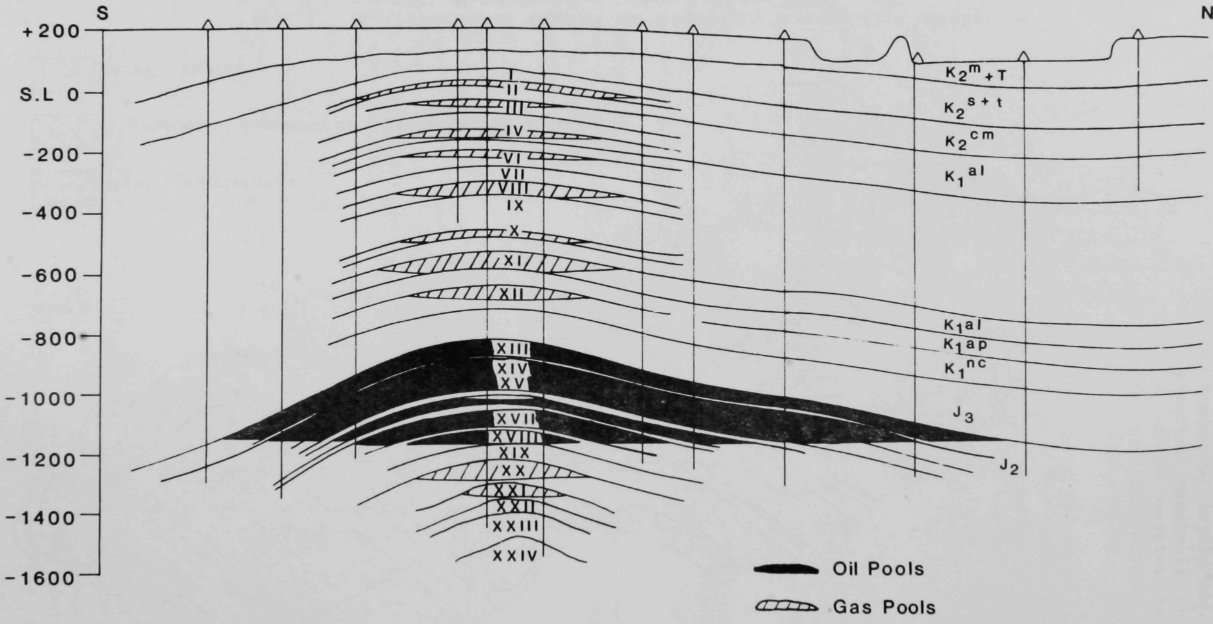


Fig. 53 Cross Section through the Main Cupola of the Uzen Field (Source: After Makhambetov, 1968)

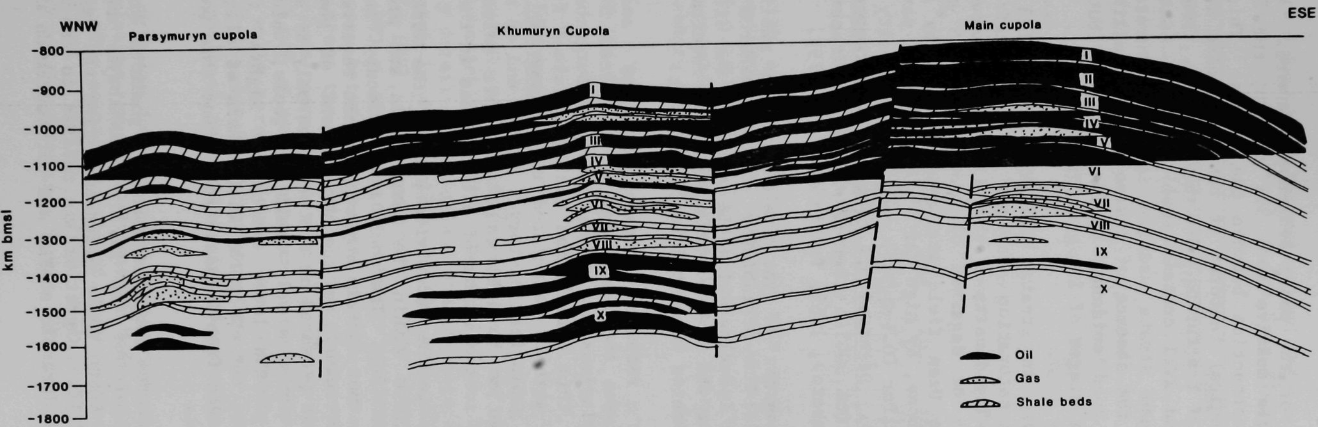


Fig. 54 Cross Section along the Long Axis of the Uzen Field Showing the Regional Nomenclature (Source: After Yuferov et al., 1975b)

Accordingly, the areas of the pools decrease downward. All of these pools together create a single massive pool 311 m high, the formation of which requires hydrodynamic connection between the strata. This connectedness is provided by the lithological features of the reservoirs and, presumably, by small faults and zones of fracturing (Chakabayev et al., 1967a). Although the pools of strata XVI and XVII contain small gas caps (Gattenberger et al., 1967), the oil of these strata usually is undersaturated by gas. This circumstance indicates the absence of thermodynamic equilibrium in the field and, consequently, is good evidence that the redistribution of the pools occurred during the last stages of its geological history.

Reservoir pressure in strata XIII-XVIII is 98-123 kgf/cm^2, or only slightly more than the saturation pressure of 75-111 kgf/cm^2. The gas-oil ratio is 61-72.7 m^3/t. The density of the oil in the reservoir is 0.763-0.777 g/cm^3, and the density of degassed oil is about 0.85 g/cm^3 (0.842-0.861 g/cm^3). Oils from the Uzen field are characterized by a predominance of methane-series hydrocarbons, by high tar (9.7-21.1%) and paraffin (up to 28%) contents, and by low sulfur (0.1-0.24%) content. Viscosity of the oil in the reservoir is 3.4-4.2 cp. Degassed oil congeals at a temperature of 25-30°C. Fractionation of crude (to 300°C) gives 27-36% light fractions and 8.9-11.3% oils (Yesenov and Makhambetov, 1965; Trebin et al., 1975).

The initial resources of the field are not published but can be estimated from Table 5. The reliability of the resource estimate depends largely on the accuracy in calculating the areas of the oil pools. Although Fig. 55 was used to make the area calculations, the results are less precise than other types of estimates presented in this report.

A comparison of the resource estimates of Tables 5 and 6 shows there is good correspondence between the percentage of resources in each stratum as obtained from our calculations and those given by Surguchev et al. (1978). Further confirmation of this calculation can be obtained from Chakabayev et al. (1977b), where the authors calculated the volume of the Uzen trap at different stages of its geological history. At the end of the Late Jurassic, the volume was estimated to be 1291 x 10^6 m^3; this volume was thought to correspond approximately to the amount of oil in place in the Uzen field.

Oil and gas pools in the underlying part of the Jurassic sequence are controlled by local uplifts within the larger fold and presumably by small faults (Yuferov et al., 1975b). The pools mainly occupy the Karamandybas and Parsymuryn cupolas and do not contain any significant reserves. Because there are no data in the literature on the development of these pools, it is presumed that they are not produced or are produced only by single wells. The main Uzen field cupola contains only small gas pools, which are located in Bajocian rocks. Oils of the lower strata are lighter (0.822 g/cm^3) and contain smaller amounts of tar and paraffin (Aleksin et al., 1969). Flows of light oil also were obtained from Triassic rocks, but this pool apparently has not been explored further.

The Cretaceous sequence contains small gas pools in strata VIII, X, XI, and XII on the main cupola of the field. Chakabayev and others (1967a) believe that the gas in these pools ascended during the degassing of oil in subjacent strata XIII-XVIII. Migration was related to the significant thinning of impermeable Upper Jurassic shales and carbonates on the Uzen cupola,

Table 5 Observed Reservoir Parameters and Calculated Oil Resources (Original Oil in Place) of the Uzen Field

Parameters	Strata						
	XIII	XIV	XV	XVI	XVII	XVIII	Total
Observed reservoir parameters							
Effective oil-saturated thickness (m)	8.7	22.8	13.6	17.6	21.8	16.0	
Area of pool (km^2)	251.7	191.4	96.8	64.5	37.6	15.1	
Saturation of connate water	0.38	0.33	0.34	0.30	0.30	0.30	
Volume coefficient	1.20	1.21	1.21	1.20	1.20	1.21	
Average Porosity (%)	21.5	21.5	21.5	21.5	21.5	21.5	
Average density of stock-tank oil (g/cm^3)	0.862	0.850	0.845	0.848	0.850	0.850	
Calculated reserves in place							
$t \times 10^6$	206.8	441.6	131.2	121.0	87.4	25.6	1013.6
$m^3 \times 10^6$	243.3	519.5	154.4	142.4	102.8	30.1	1192.5
% of total	20.4	43.6	12.9	11.9	8.7	2.5	100

Sources: Trebin et al., 1975; Bykov et al., 1967; Valeyeva et al., 1967; and Tsvetkov, 1967.

which contrasts with other structures in the region. The gas of these strata is 71-98% methane (average 93%), 1.8-7.6% nitrogen, 0.12-2.0% carbon dioxide, and 0.024-0.016% helium (Ayazbayeva, 1968; Yesenov and Makhambetov, 1965). Total recoverable gas reserves in the Cretaceous section are about 7.8×10^9 m^3 (Chakabayev et al., 1967a).

8.4 DEVELOPMENT OF THE FIELD

8.4.1 History of Discovery

The Uzen anticlinal structure was inferred from surface geological mapping by S.N. Alekseichik in 1941. Details of the structure were confirmed during 1950-1954 by detailed mapping and shallow core drilling. Core drilling to depths of several hundred meters in the area of the Zhetybay and Uzen anticlines began in 1957, contemporaneously with areal geophysical investigations. Some 395,000 m of seismic profiles were run using the reflection method. The distance between transverse profiles was 2.5-4 km; longitudinal profiles were run along the axis and flanks of the structure. The amount of deep core drilling was comparatively small. Forty-six wells, having a total length of about 12,000 m and a maximum depth of 985 m, were drilled. The distances between wells were 2-4 km. Core samples were taken from marker beds. These activities detailed the structure on Cretaceous horizons and in 1960 revealed gas pools of commercial significance in the Cretaceous sequence of the Uzen field.

Deep drilling began in 1961. The first wildcat (No. 1), which was near the crest of the closure, penetrated clastic beds in the Callovian and Middle Jurassic sequence. The section contained several tens of beds and intercalations saturated by oil. Testing of this well proved the presence of an oil pool in stratum XVI of the Bathonian Stage. The next three wells chosen for

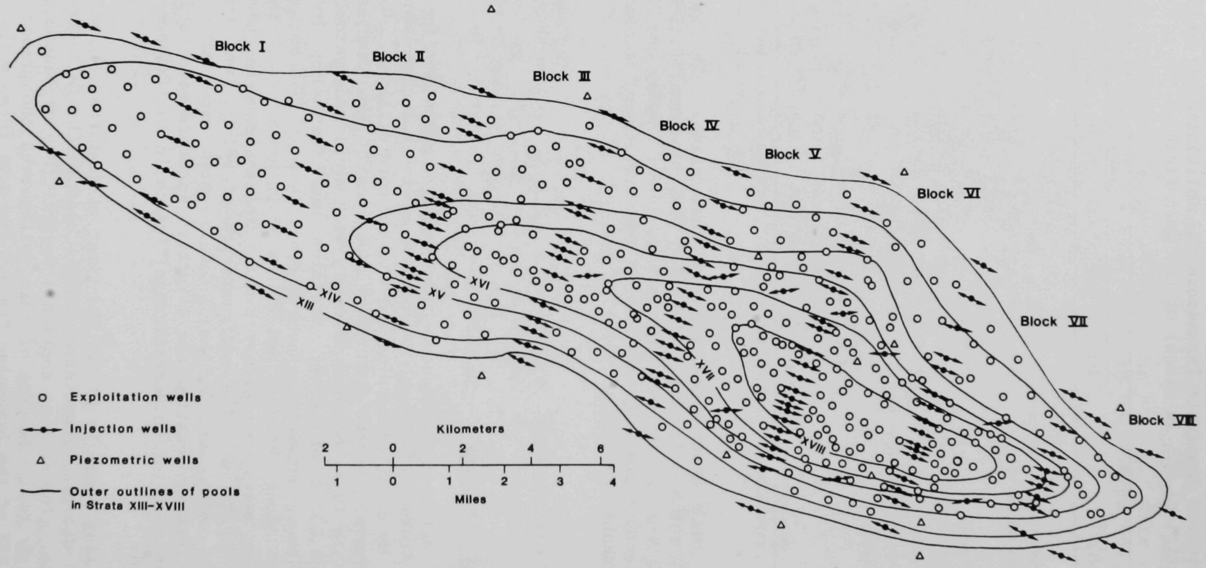


Fig. 55 Distribution of Wells on the Uzen Field (every second well is shown) (Source: After Bykov et al., 1967)

Table 6 Distribution of Proved Reserves of the Uzen Field in Reservoirs of Different Permeability

Intervals of Permeability (md)	Strata						
	XIII	XIV	XV	XVI	XVII	XVIII	Total
10-20	14.0[a]/32.4	6.9/34.8	6.2/9.2	4.5/5.2	12.9/15.2	10.0/3.2	8.7/100.0
20-50	15.6/24.5	10.1/34.6	17.2/17.5	11.2/8.8	10.9/8.8	26.8/5.9	12.8/100.0
50-150	24.7/16.0	28.7/40.8	42.5/17.9	36.8/11.9	29.7/9.9	37.8/3.5	30.8/100.0
150-400	22.5/16.8	30.2/49.1	21.7/10.5	33.9/12.5	25.9/9.8	10.7/1.2	27.0/100.0
>400	23.2/22.8	24.0/50.8	12.3/7.7	13.6/6.6	20.4/10.1	14.7/2.0	20.7/100.0
Total	100.0/20.1	100.0/43.8	100.0/13.0	100.0/10.0	100.0/10.2	100.0/2.9	100.0/100.0

[a]The numerator is the percentage of proved reserves in each stratum; the denominator is the percentage of proved reserves in intervals of permeability.

Source: Surguchev et al., 1978.

testing (Nos. 2, 5, and 22) confirmed the presence of other pools and made it possible to distinguish strata XIII, XIV, XV, XVI, and XVII. These strata form the main oil-bearing complex of the structure. Thus, excluding the period of World War II, more than 15 yr passed between discovery of the anticlinal fold and proving of the oil field. The discovery of the field happened at a time when the addition of oil reserves in the Volga-Ural area had sharply decreased; the new discovery stimulated rapid development of exploratory activities in this new oil-producing region. As indicated by Rozenberg and Golubkov (1968), it was believed that the South Mangyshlak area would yield 35-50 x 10^6 t-oil/yr by 1980.

8.4.2 Exploration of the Uzen Field

Three main factors determined the method of exploration of the field: (1) the considerable thickness of the productive sequence, (2) the relatively large number of oil-saturated beds needing separate testing, and (3) pressure from the government to exploit the field as rapidly as possible.

The gas prospects of the Cretaceous section were initially evaluated as very high, and the Uzen field was considered to be mainly gas-bearing. The drilling of 14 exploratory wells showed, however, that the gas pools did not extend beyond the main cupola and that gas reserves were only 7.8 x 10^9 m^3 (Chakabayev et al., 1967a).

Exploratory drilling in the Uzen field began in 1962 on the basis of data obtained from the first four wildcats. The drilling project consisted of two phases -- preliminary and detailed. In the preliminary phase, 26 wells with a total length of 43,050 m were drilled to depths of 1450-2500 m (Makhambetov, 1968). Two exploration horizons were recognized. The upper horizon included strata XIII-XVIII, which occur at depths of 1100-1450 m. This complex was classified as "major." The lower horizon included the underlying sequence, where pools had not yet been discovered. The detailed phase of drilling called for 30 wells having a total length of 43,500 m. Wells were to be drilled along a series of transverse profiles, which were to begin at the crest of the fold and proceed to its flanks. The distance between the profiles was to be 3.5 km; the distance between wells on an individual profile was to be 2-2.5 km.

During the preliminary phase, the actual distance between profiles was usually 3-5 km. From the very first, the State plan for proving reserves had to be carried out rather than the comprehensive exploration plan. This meant that some of the wells of the second phase were drilled during the first phase (Aleksin et al., 1969). Since drilling was concentrated on the major Uzen cupola, delineation of the pools in strata XIII and XIV was significantly delayed. Detailed outlining of pools was accomplished during preparation of the field for experimental exploitation by drilling advanced appraisal-development wells. The preliminary phase of exploration was completed by the beginning of 1964.

During the detailed phase of exploration, wells were placed on profiles between the profiles of the earlier phase. This reduced the distances between profiles to 1.75-2.0 km and the distances between wells to 1.5-2.2 km. Emphasis was placed on the flanks and periclines of the fold. As a result, the extent of the main pools in strata XIII and XIV of the Karamandybas area was outlined and the pools in strata XX and XXI were discovered. By the beginning of 1966, 59 exploratory and appraisal-development wells having a total length of 87,400 m had been drilled, and 187 units in strata XIII to XVIII had been tested. At the end of the exploration phase, proved reserves were 58% of total recoverable reserves (Aleksin et al., 1969). The Uzen field was then turned over to development and exploitation. Because the Karamandybas part of the field (see Fig. 49) had been explored more slowly due to the increased depths of the main pay zones and the deterioration of the reservoir properties of the beds, this portion was not ready for development activity until 1968.

8.4.3 The First Phase of Development

The main plan for development and exploitation of the Uzen field was set forth in 1965. As discussed by Bykov et al. (1967), Yegurtsov et al. (1968), and Yegurtsov and Orlov (1968), the main aspects of the development plan were as follows:

1. The main plan would be for the field as a whole and not for separate strata.
2. Production units would be enlarged. The first unit would be strata XIII and XIV; the second unit, strata XV and

XVI; the third unit, stratum XVII; and the fourth unit, stratum XVIII. Simultaneous-separate exploitation* and water flooding were contemplated.

3. Reservoir pressure would be maintained from the very beginning of production.

4. The main production units of the field would have to be sectioned into blocks 4 km wide by injection wells (see Fig. 55). The blocks would be designed to prevent fluid flow from one stratum to another.

5. Hot water would be injected at the beginning of production, and the border of hot water would be forced out by flooding with cold water. In the experimental area of stratum XVI, oil would be forced out by injection of enriched gas.

6. Production would begin in additional blocks as soon as they would be ready for exploitation.

7. Density of the wells in the development grid would be 42 ha per well (600 x 700 m) for the first production unit and 33 ha per well (550 x 600 m) for the second unit. Together with reserve wells, the density would be 34 and 28 ha per well, respectively. In each block, five rows of development wells would be completed in the first unit and seven rows in the second unit (see Fig. 55). Distances between injection wells would be 500 m in the first unit and 250 m in the second.

8. The third unit would be produced by flooding outside the oil-water contact; density of the well grid would be 45 ha per well.

9. The fourth unit would be exploited without maintaining reservoir pressure; density of the well grid would be 45 ha per well.

10. Rows of development wells would be offset so that on the surface the field would be covered by a grid of wells that gradually changed from 42 ha per well on the flanks to 12-20 ha per well near the crest of the fold.

11. This exploitation plan would be characterized by the following average indexes for the first five years of exploitation:

Development wells	810
Injection wells	251
Total wells	1061
Average annual output of oil (10^6 t)	20
Average annual output of fluid (10^6 t)	29

*Simultaneous-separate exploitation involves disconnecting two strata in a unit by using a packer.

Average yield of oil per well (t/d)	71
Average yield of fluid per well (t/d)	98
Average annual injection of water (10^6 m^3)	34.7

After an initial small correction in the above plan at the beginning of development, the number of development wells was changed to 788 and the number of injection wells to 259. Some 431 wells had to be equipped for simultaneous-separate exploitation, and 194 wells had to be equipped for simultaneous-separate flooding. The disposition of the wells is shown in Fig. 55.

Exploitation of the Uzen supergiant has been plagued by many difficulties, the most important of which are related to: (1) the large area of the field, (2) the strongly heterogeneous reservoir properties of producing strata, (3) the high paraffin content of the oil, and (4) the closeness in value of reservoir pressure and saturation pressure. These characteristics required a very careful approach to exploitation, especially during the first phase.

We will now consider the development of the field in the first phase and try to show how exploitation during this phase caused deterioration of the productive capacity of the field. The most comprehensive of the available data come from mid-1967, two years after the beginning of exploitation.

Drilling rates in the Uzen field, as in the entire Mangyshlak region, were low. In 1964-1965, each rig drilled an average of only 800 m/mo, at a time when the average depths of the wells were to be 1300-1600 m (Rozenberg and Golubkov, 1968). When labor efficiency did not improve, an increase in the amount of drilling was achieved only by increasing the number of rigs. By April, 1967, the drilling of development and injection wells on strata XVII and XVIII was almost complete. Twenty-five wells were drilled on stratum XVIII, and 16 of them were placed in production. The daily yield of oil was 972 t, and total output from the beginning of production was 183.1 x 10^3 t. Reservoir pressure declined from 124.2 kgf/cm^2 to 118.6 kgf/cm^2 (Dmitriyev et al., 1967).

Fifty-six wells were drilled to stratum XVII. Forty of these were placed in production and 16 did not produce. The average yield per well was 66 t/d, and total output from the stratum reached 780 x 10^3 t by mid-1967. Reservoir pressure decreased 4-6 kgf/cm^2. Water flooding began in January, 1967; by April, 11 of the 16 planned wells were operative. The volume of injected water was about 300 m^3/d and was greatly limited by a water shortage. Heating of water for flooding was not realized. The ratio of injected water to oil produced varied from 0.8 to 1.2.

Of the 473 projected output wells in the first unit (strata XIII and XIV), only 60 wells had been drilled by April, 1967. Of the 140 planned injection wells, only 7 had been completed by that date (Bykov et al., 1967). Of 49 wells in production, 18 produced from stratum XIII, 22 from stratum XIV, and 9 from strata XIII-XIV. Each of the wells completed in stratum XIV had a flowing regime and yielded an average of 50-70 t-oil/d. Total output from the stratum was 540 x 10^3 t. Reservoir pressure decreased 2-4 kgf/cm^2. Yields of wells from stratum XIII varied widely from 15 to

200 t/d. High yields were realized in the western part of the pool, where the thickness of the reservoir reaches 25-40 m, compared with an average thickness of 11-12 m for the whole pool. The reservoir pressure decreased in most wells by 4-6 kgf/cm^2. Dmitriyev et al. (1967) considered this to be the result of the lenticular structure of the reservoir.

By the middle of 1967, the major problems standing in the way of proper development of the field had not been solved. Equipment for simultaneous-separate exploitation and injection had not been ready on time and was barely being tested by 1967 (Orzhanov et al., 1967). Cement work on wells was of poor quality (Samuelyan and Mullayev, 1967); in 1965, 25 wells were found to have defective cement work. The defective cement condition was a result of low reservoir pressure and required a change in specifications to substitute a lighter type of cement for the standard kind. In addition, many drilled wells had not been completed in a timely fashion due to lack of equipment, which led to deterioration of reservoir properties at the bottoms of the wells. In many cases, it was impossible to obtain a natural oil flow; these wells had to be pumped. Further, the problem of water supply had not been solved, which created a significant shortage of injection water (Osadchiy et al., 1967).

Improper development of the field and a long delay in implementation of pressure maintenance was accompanied by intensive production of oil, usually with a bottom hole pressure lower than the pressure of saturation. Petroleum geologists warned about the adverse consequences of such exploitation. During the first two years of production, field and laboratory experiments revealed three main factors that threatened premature depletion of the field and decreasing oil recovery efficiency. The first of these was the rapid increase of the gas-oil ratio in produced oil, which indicated degassing in the oil reservoir and creation of an artificial gas cap. The danger of replacing the water-drive regime with a less-effective dissolved-gas drive regime became apparent (Aleksin et al., 1969). Furthermore, Kovalev et al. (1967) and Abramov et al. (1967) showed that degassing of the oil reservoir would lead to crystallization of paraffin. Such an increase in oil viscosity would lead to a sharp increase in filtration resistivity and to a decrease in sweep efficiency. Therefore, proper production of the field without maintenance of reservoir pressure would become impossible (Bykov et al., 1967).

The second factor that appeared during the early stages of development of the field was related to maintaining reservoir temperature. Precipitation of paraffin from Uzen oil begins at 50-55°C, a temperature only slightly less than reservoir temperature. At 29-30°C, the oil completely congeals (Utebayev et al., 1968). Because the rate of flow of water injected into an heterogeneous reservoir is much higher in the more permeable beds, cold injection water can cool adjacent, less permeable beds to 40-45°C (Avdonin and Orlov, 1967; Utebayev, 1969). Once the filtration resistivity has risen sharply due to cooling, restoration of filtration requires a pressure gradient much higher than the gradients achieved during production (Abramov et al., 1967). This results in a sharp reduction in the displacement efficiency of oil and can mean the complete plugging of less permeable beds. In addition, cooling of rocks at the bottom of injection wells can result in reservoir plugging and reduced injection capacity, which could threaten the entire plan of pressure maintenance (Avdonin and Orlov, 1967). Artificially reduced bottom-hole and reservoir temperatures restore very slowly (Utebayev et al., 1968).

The third important complication in the exploitation plan was related to the injection of water into selected reservoir beds. Initial investigations had shown the thinness and irregularity of the injectable intervals (Osadchiy et al., 1967). Increasing the pressure at a wellhead resulted in only a slight increase in overall effect, because injectability was found to be a function of the more permeable intercalations (Utebayev et al., 1968). Since beds or groups of beds with different permeability required different injection regimes, they had to be separated by packers. This was the only way to obtain a more or less even front of injected water (Stukanogov, 1967).

None of these three problem areas were resolved on time, and some of them have yet to be resolved. These failures influenced subsequent production and, evidently, the recovery efficiency of the Uzen field.

8.4.4 Subsequent Development

Intensive development of the Uzen field continued after 1967. In June, 1968, injection of cold water was started in the wells of block III (see Fig. 55). In 1970 injection was begun in the wells of blocks II and IV. By 1972 large flooded zones had been created in the central and eastern parts of the field in the areas of these three blocks. Fifty percent of the wells of the first unit (strata XIII and XIV) and 70% of the wells of the second unit (strata XV and XVI) had watered out (Leybin et al., 1975). The water content of the oil produced by most wells was 10% or more. By the end of 1971, reservoir pressure in zones of extraction had continued to decrease to the point where reservoir pressure was 20-30 kgf/cm^2 less than the saturation pressure. This resulted in development of a dissolved-gas drive regime in the internal parts of the pools (Yuferov et al., 1975a). In spite of the large volume of water injected by 1974, these areas of degassing remained, i.e., phase equilibrium was not restored. Reduction of reservoir pressure resulted in a greater than twofold increase in the gas factor of produced oil and in precipitation of paraffin, mostly in less-permeable beds (Melik-Pashaev, 1973). As a result, many of the producing wells showed a sharp decline in their daily output and productivity factor (Smolnikov et al., 1974).

In 1972 it had become clear that the exploitation system needed significant improvement. It was decided to section the field further into blocks 2 km wide, to increase the density of producing wells, and to make the production units smaller. Experimental injection of hot water in the end of 1971 had shown the feasibility of this process (Melik-Pashaev, 1973), but it was not implemented at that time, probably for economic reasons.*

Peak production from the Uzen field was evidently reached during 1975-1976. Although annual production figures are not available, production can be estimated using data from Timashev et al. (1978). At the beginning of 1976, strata XIII and XIV were exploited by 812 wells, 93% of which were watered out. In June and July, 1976, it was decided to begin forced extraction of fluid. On September 1st of that year, the average yield per well was 39.2

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*During 1979 only 31% of injected water was heated (Safronov et al., 1980). As of January 1, 1980, 300 x 10^6 m^3 of cold water had been injected into strata XIII-XVIII. Reservoir temperature had decreased by 5-20°C and more.

t-oil/d and 29.3 t-water/d. This meant that the watering-out of wells had increased from 26.1% at the beginning of the year to 42.8%. Oil production from strata XIII and XIV did not increase significantly; in fact, it did not exceed 3-4 x 10^3 t/d. At the same time, the 1976 total output of fluid from the field was 73.4 x 10^3 t/d. Watering-out of strata XV and XVI was about the same as in superjacent strata; in strata XVII and XVIII, it was not significant in the total output of the field. Based on these data, the annual yield of the field in 1975-1976 is estimated at 15.0-15.5 x 10^6 t of oil, 11.6 x 10^6 t of which were obtained from strata XIII and XIV. This estimate coincides well with that of Dienes and Shabad (1979); they evaluated the total output of the field in 1975 at 16 x 10^6 t of oil.

The main difficulty in proper development of the Uzen field is the marked nonuniformity in reservoir permeability. Because of this factor, the chosen system of exploitation of large units resulted in ineffective flooding. The projected recovery efficiency of 45% for the Uzen field, with a displacement efficiency of 0.6, had been assumed by the planners as being capable of achievement at a volumetric sweep efficiency of 70-75% (Leybin et al., 1975). The virtual impossibility of achieving such a sweep efficiency became clear by 1972, based on data from the first rows of injection wells. The intensive expansion of the flooding zone, with concomitant ineffective sweep of oil by water, was reported by Leybin et al. (1975). Breakthrough of water to a well took place along very narrow intervals (0.5-2.0 m). Total watered-out thickness was extremely low and varied from 2 to 5 m (Ilyaev et al., 1975a), which is only 5-10% of the effective thickness of the reservoir strata. Only 1-3% of the beds with permeabilities as high as 50 md watered out. Beds with permeabilities of 50-300 md were only 7-18% watered out. Most of the watered-out beds had permeabilities of more than 300 md. The same situation evidently holds today. Repeated attempts to increase the number of working beds by using different methods of stimulation have not met with significant success (Smolnikov et al., 1974 and 1976; Ilyaev et al., 1975b). For the most part, intensive depletion of highly permeable (more than 300 md) reservoir beds continued. Most beds with permeabilities less than 150 md did not water out (Zharkova et al., 1979). Average producing thicknesses in wells were 30-60% of the effective thickness of the perforated reservoir strata (Leybin et al., 1978).

It is clear from the above that the exploitation of this supergiant field has been affected by very complicated geological conditions and aggravated by forced production in the initial phase of development. It is certain that the initially projected recovery efficiency will not be achieved, although the Soviets still have possibilities for improving this situation to some degree (Ivanchuk et al., 1979; Leybin et al., 1978).

The recovery efficiency of this field can be estimated using Table 6. During exploitation of a pool under conditions of a strong water drive regime, the recovery of oil is proportional to displacement efficiency and volumetric sweep efficiency. For reservoir rocks of different permeability in the Uzen field, displacement efficiency has been evaluated by Leybin et al. (1975) as 60%. Although displacement efficiency decreases due to precipitation of paraffin in less permeable layers, it is not sufficiently important to be considered in the total evaluation. Therefore, assessment of recovery efficiency depends on evaluating the sweep efficiency. The data presented thus far allow specification of the following upper and lower values of sweep efficiency:

Permeability (md)	Volumetric Sweep Efficiency (lower/upper)
10-20	0.0/0.1
20-50	0.0/0.2
50-150	0.3/0.6
150-400	0.6/0.9
>400	0.9/1.0

The most recently published data show that the lower values are much more probable now. For example, reservoir layers with permeabilities less than 50 md are very probably not amenable to waterflooding (Surguchev et al., 1978). Increasing the sweep efficiency will require additional investment related to activities like focus water flooding, heating of injection water, and exploration for oil left behind.

Calculated recoverable reserves of oil in the Uzen field are given in Table 7. For stratum XVIII, which has been exploited without maintaining reservoir pressure, the recovery efficiency for conditions of low reservoir energy is 0.2.

For the complicated geological conditions of the Uzen field, Table 7 shows that recovery efficiency is 25.7-39.1% This range of values is highly probable from our point of view. Our assessment of recoverable oil reserves is significantly less than that of Halbouty et al. (1970), whose estimate was 580 x 10^6 m^3. Their figure implies a recovery efficiency of 48.6%, a value close to the initial plans of the Soviets but now rather unrealistic.

The rate of oil extraction in the first stage of production depends only slightly on the assessment of total recoverable reserves, because production during the first years increases mainly due to intensive working of the most permeable reservoir rocks. During subsequent exploitation, field output declines as the rate of watering-out increases. This phase of exploitation appears to have already begun.

Surguchev et al. (1978) evaluated the rate of watering-out using a model in which all pay zones are presented as a single stratum comprising several beds of differing permeabilities. For every interval of permeability, the thickness of each bed corresponds to the total effective thickness of real layers in the field. When the recovery of 66% of reserves is achieved, Table 8 shows that the water cut of production will reach almost 90%; that is, 9 m^3 of water will be produced with every cubic meter of oil. Table 8 assumes a high (0.5-0.6) sweep efficiency for reservoir layers with lower permeability. At lower sweep efficiencies, the rate of watering out during the last stages of exploitation will be even higher. On January 1, 1980, the water cut of oil production for the Uzen field reached 58% (Safronov et al., 1980).

Table 7 Recoverable Oil Reserves (proved reserves) of the Uzen Field (10^6 m^3)

Intervals of Permeability (md)	Strata						Total
	XIII	XIV	XV	XVI	XVII	XVIII	
10-20	0/2.0 [a]	0/2.2	0/0.6	0/0.4	0/0.8		
20-50	0/4.6	0/6.3	0/3.2	0/1.9	0/1.3		
50-150	10.8/21.6	26.8/53.7	11.8/23.6	9.4/18.9	5.5/11.0	6.0	
150-400	19.7/29.6	56.5/84.7	12.1/18.1	8.7/17.4	9.6/14.4		
>400	30.5/33.9	67.3/74.8	10.3/11.4	10.5/11.6	11.3/12.6		
Total	61.0/91.7	150.6/221.7	34.2/56.9	28.6/50.2	26.4/40.1	6.0	306.8/466.6
Percentage of total oil in place							25.7/39.1

[a]The numerator is the lower assessment of recoverable reserves; the denominator is the upper assessment.

Table 8 Watering-Out of Production as a Function of Relative Oil Recovery

Relative Oil Recovery (% of ultimate production)	Water Cut of Production (%)
26.8	38.3
39.1	65.6
66.1	88.9
76.8	91.8
98.4	97.6
100.0	99.4

Source: Surguchev et al., 1978.

9 RESOURCE ASSESSMENT

9.1 EVALUATION OF BASIN POTENTIAL

The Middle Caspian Basin includes several geologically diverse regions. The petroleum resources of these regions, their degree of exploration, and their production potential vary widely. Following the classification of Halbouty et al. (1970), the Middle Caspian Basin contains five giant and supergiant oil fields and one giant gas field. Three of the giant oil fields are located in the Terek-Sunzha region and two of them are in the South Mangyshlak region. Recoverable oil reserves for each of these fields are more than 80 x 10^6 m^3. Two others, the Karazhanbas and possibly the North Buzachinskoye oil fields on the Buzachi peninsula (North Ustyurt Basin), are of similar size.

The Middle Caspian Basin includes some areas with a long history of exploration and geological study. The probability of significant new discoveries in these areas is small, except perhaps in as yet unexplored, deeply buried sedimentary rocks. However, vast areas, especially beneath the Caspian Sea, remain unexplored. The potential for significant finds in these areas is rather large.

A petroleum resource assessment of the Middle Caspian Basin requires refinement of the general definition of the word "resources" given on p. *ix*. We define "resources in place" as the initial amount of liquid petroleum and/or gas contained as pools in the earth's crust, independent of current exploitability. "Specific resources" are the initial resources in place per unit volume of sedimentary or reservoir rocks.

Recovery efficiency for petroleum resources will depend on many geological factors, as well as the size of pools and the technology applied. Over large regions, the average recovery efficiency is 30-40% of estimated resources in place. In some cases, recovery efficiency can be estimated more precisely based on geological comparisons. Because data on resources in place and recoverable reserves are not published in the USSR, we could only approximate resources in place for the land areas of the basin. This evaluation rested on: (1) areal extent of productive structures, (2) their number, (3) the stratigraphic intervals of productivity, and (4) standard terminology for fields used widely in Russian publications (e.g., small, average, large (or rich), largest, and giant). Average figures for the amount of oil and/or gas in place for "small" fields were taken to be 20 x 10^6 t; for "average" fields, 50 x 10^6 t; and for "large" fields, 100 x 10^6 t. Recoverable reserves of the "largest" and "giant" fields were evaluated more exactly by converting Halbouty et al. (1970) figures for the amount of oil in place using recovery efficiencies of 35%. Our resources-in-place estimates for productive regions of the basin are shown in Table 9. Two fields, Uzen (South Mangyshlak region) and Malgobek-Voznesenskoye (Terek-Sunzha region), are shown as giant, with the amount of oil in place for each field estimated to exceed 1 x 10^9 t.

Qualitative assessments of the resource potential of the Middle Caspian Basin are found in many publications. Probably the most exhaustive study of the potential of the basin was made by Polster et al. (1972). Structural, lithological, hydrogeological, and geochemical factors were considered to be

Table 9 Resources in Place of Productive Regions of the Middle Caspian Basin

Productive Region	Predominant Hydrocarbon	Number of Fields: Small	Average	Large	Largest	Giant	Coefficient of Exploration*	Oil and/or Gas Discovered--Resources in Place[a] (10^6 t)
North Stavropol	gas	←12→		1	1	-	>0.9	400
Arzgir-Prikumsk	oil	28	5	5	-	-	0.5	1310
Terek-Sunzha	oil	8	7	2	3	1	0.6	2430
South Dagestan	oil and gas	8	1	2	-	-	0.3	310
Karpinskiy Ridge	gas	3	2	1	-	-	0.9	260
South Mangyshlak	oil and gas	7	1	1	1	1	0.9	1790
Buzachi	oil	-	2	1	1	-	?	1000
North Ustyurt	oil	1	1	-	-	-	?	70
Total								7570

[a]One metric ton of oil equals 1000 m^3 of gas.

Source: After Dikenshtein et al. (1977).

the main factors controlling resource potential. Qualitative assessments, however, suffice only for management of exploration programs and not for evaluation of possible future production.

We used three methods to evaluate resources in place for the Middle Caspian Basin. The first two (volumetric and reservoir-volumetric) are based on analogy; that is, the Middle Caspian Basin was compared with groups of similar basins. The third method (volume-genetic) is based on calculations of the amounts and types of hydrocarbons generated in the sedimentary sequences in this basin.

9.1.1 Volumetric Method

The theoretical basis for this method is the well-known relationship between the size of a basin and the quantity of oil and gas that it contains. For unexplored basins, the specific resources per unit of volume of sedimentary rocks are determined by comparison with an explored basin (or group of basins) similar to the basin under investigation. Because the comparison is based on geological analogy, the reliability of the results depends on the choice of the reference basin(s). As a rule, more reliable figures are obtained from calculations based on a group of similar basins. Halbouty et al. (1970) estimates that 40,000-170,000 bbl of oil/mi^3 of sedimentary rocks (average: 100,000 bbl) can be recovered from basins like the Middle Caspian Basin (cratonic type II). Conversion of these figures to specific resources gives 3,700-15,600 t/km^3 (average: 9,200 t/km^3) of specific resources in place, assuming a recovery efficiency of 35%.

A more interesting approach to evaluating specific resources can be found in an article by Nalivkin et al. (1976). On the basis of statistical calculations for 35 well-studied basins, they demonstrated that specific resources in place and several major geological characteristics of a basin can be quantitatively correlated (see Fig. 56). The method is called "the weakest

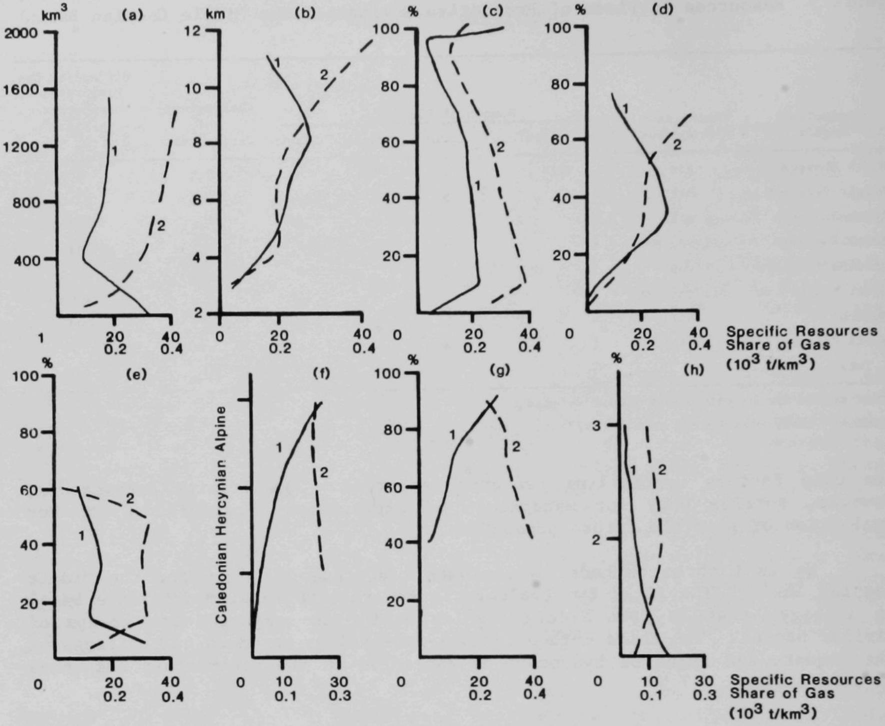


Fig. 56 Dependence of Specific Resources (1) and Gas-Oil Ratio of Resources (2) on: (a) Size of a Basin, (b) Thickness of Nonfolded Phanerozoic Sedimentary Rocks, (c) Scale (%) of Mesozoic-Cenozoic Subsidence, (d) Volume (%) of Sedimentary Rocks Subsided More Than 2 km, (e) Volume (%) of Carbonate Rocks to Total Volume of a Basin, (f) Age of Oil and Gas-Bearing Complex, (g) Volume (%) of Marine Rocks to Total Volume of a Basin, and (h) Number of Complexes (Alpine, Hercynian, and Caledonian) (Source: After Nalivkin et al., 1976)

link" and involves choosing the smallest value for specific resources obtained by comparing the characteristics of the basin under study with the curves of Fig. 56. For the Middle Caspian Basin, the "weakest link" is the volume of the basin. Therefore, the maximum value for specific resources in place is 18,000 t/km^3 of sedimentary rocks. Approximately the same figure is obtained from curve d in Fig. 56, because 56% of the sedimentary sequence has subsided deeper than 2000 m in the Middle Caspian Basin.

The total volume of sedimentary rocks of the platform cover in the Middle Caspian Basin is 1,538,700 km^3 (see Fig. 57). This figure does not include Triassic rocks and small, insignificant parts of the basin beyond the area under investigation. Accepting the Halbouty et al. (1970) value for specific resources, we obtain a value (upper limit) for resources in place of 24 x 10^9 t, an average value of 14.2 x 10^9 t, and a lower value of 5.7 x 10^9 t. The Nalivkin et al. value would have been 27.7 x 10^9 t. It is possible to narrow this wide range of values by a simple comparison. The total volume of sedimentary cover in the oil- and gas-bearing regions of the Middle Caspian Basin is 669,000 km^3. (This includes the volume of sedimentary cover of all land areas except the Karabogaz region.) Total discovered resources in place in the basin are close to 6.5 x 10^9 t. To estimate total resources in place of the land areas, it is necessary to use the coefficients of exploration for each region (see Table 9). These coefficients are believed to be based on detailed assessments of resource potentials by Soviet specialists (Dikenshtein et al., 1977). The calculated amount of discovered and undiscovered resources in place for the land areas is 10.4 x 10^9 t. This figure may be slightly exaggerated, as the coefficients of exploration include resources of Triassic sedimentary rocks that are not included in the calculation. This factor is significant only for the Arzgir-Prikumsk region, where 40% of undiscovered resources are associated with this sequence. After suitable correction, we consider the figure of 10.15 x 10^9 t to be reliable. This figure yields average specific resources of 15,200 t/km^3 of sedimentary rocks and lies between the average value for specific resources of Halbouty et al. (1970) and that of Nalivkin et al. (1976). Assuming that this value is reliable, total undiscovered resources in place for the platform cover of the Middle Caspian Basin are 16.4 x 10^9 t (without the Karabogaz land area), 12.7 x 10^9 t of which are for the part of the Caspian Sea within the basin boundaries.

This assessment is only an approximation, because it ignores geological differences between various parts of the Caspian Sea area. A more detailed assessment of resource potential is possible if these different parts are evaluated separately, i.e., if each of them is compared with geologically similar land areas. The regions delineated for this exercise are shown in Fig. 58a, and the basic data are compiled in Table 10. Outlining of the regions is based on similarity of structural conditions (see Sec. 2.2.3) and the sedimentary sequence, especially for the main productive complexes (see Sec. 3). As can be seen in Table 10, total resources in place beneath the Caspian Sea are slightly less than those calculated by considering the region as a whole (10.7 x 10^9 t versus 12.7 x 10^9 t).

The evaluation of resources may be detailed further if an analogy ratio is taken (see Table 11) that reflects: (1) the degree of similarity of the land and sea parts of each region and (2) the improvement or deterioration of conditions for hydrocarbon accumulation and conservation. (If the value for

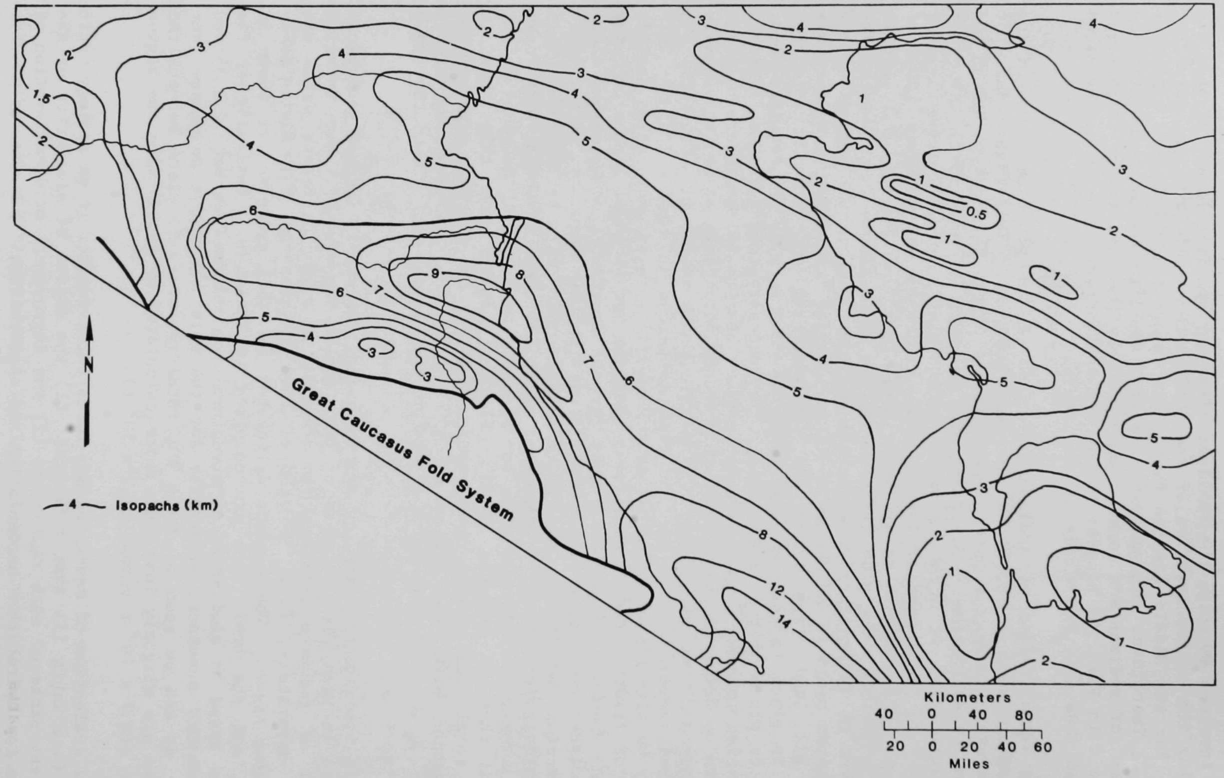
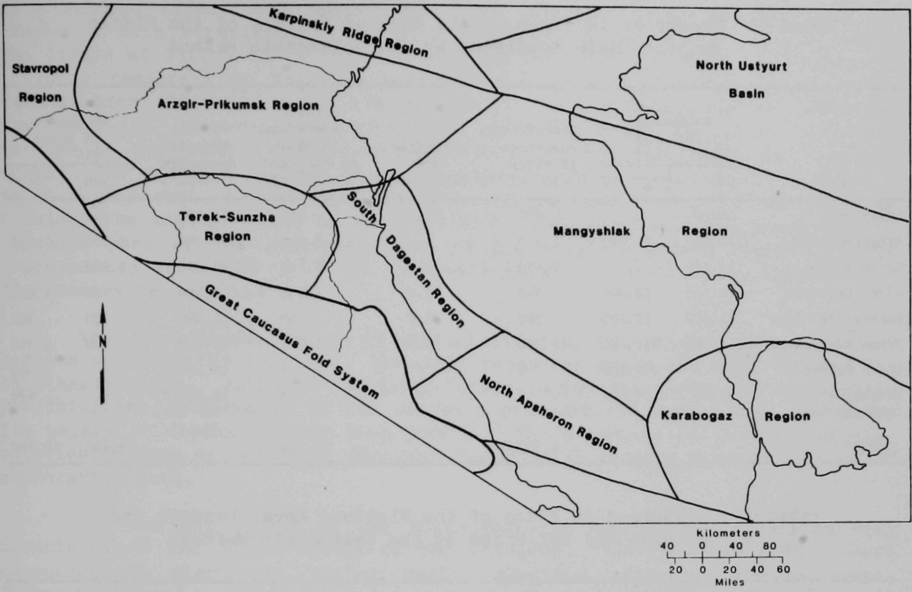


Fig. 57 Thickness of the Platform Cover (Source: After Polster et al., 1972)

a.



b.

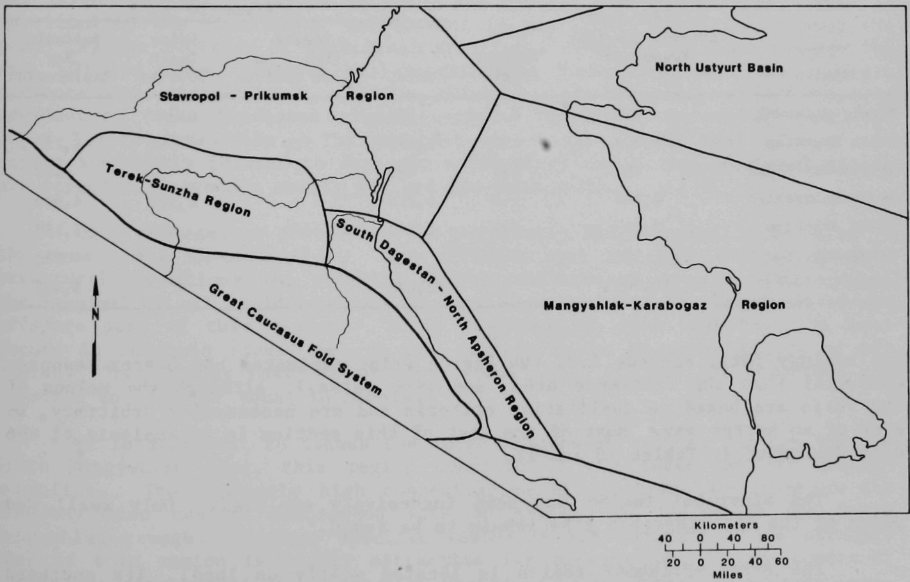


Fig. 58 Regions for Resource Evaluation

Table 10 Resources in Place of the Various Regions of the Middle Caspian Basin Estimated by the Volumetric Method

Region	Volume of Sedimentary Rocks (km^3) Land	Volume of Sedimentary Rocks (km^3) Sea	Discovered Resources in Place (10^6 t)	Coefficient of Exploration	Total Resources in Place on the Land (10^6 t)	Specific Resources (t/km^3)	Undiscovered Resources in Place (10^6 t) Land	Undiscovered Resources in Place (10^6 t) Sea
Stavropol	40,200	-	400	0.9	440	11,100	40	-
Arzgir-Prikumsk	240,600	74,900	1,310	0.5	2,620	10,900	1,310	820
Terek-Sunzha	134,800	-	2,430	0.6	4,050	30,000	1,620	-
South Dagestan	76,700	78,000	310	0.3	1,030	13,400	720	1,050
Karpinskiy Ridge	13,600	17,700	260	0.9	290	21,300	30	380
South Mangyshlak	163,100	391,600	1,790	0.9	1,990	12,200	200	4,780
North Apsheron	-	202,600	0	-	0	15,200(?)	-	3,080
Karabogaz (without bay)	32,900	39,000	0	-	0	15,200(?) for sea only	-	590
Total			6,500		10,420		3,920	10,700

Table 11 Resources in Place of the Platform Cover beneath the Caspian Sea Estimated by the Volumetric Method

Region	Assessment of Resources in Place from Average Specific Resources (10^6 t)	Analogy Ratio	Corrected Value of Resources in Place (10^6 t) Total	Deeper than 7 km below Surface	Water Depth >0.4 km	Suitable for Exploration
Arzgir-Prikumsk	820	0.7	570	-	-	570
South Dagestan	1,050	2.0	2,100	220	150	1,730
Karpinskiy Ridge	380	1.2	460	-	-	460
South Mangyshlak	4,780	1.3	6,210	-	1,310	4,900
North Apsheron	3,080	0.7	2,160	530	480	1,150
Karabogaz	590	1.0	590	-	-	590
Total	10,700		12,090			9,400

the analogy ratio exceeds 1.0, the region being evaluated has better resource potential than the reference area, and vice versa.) Although the values of the ratio are based on qualitative criteria and are necessarily arbitrary, we know of no better way. Most of the rest of this section is an analysis of the data presented in Tables 10 and 11.

The Stavropol region has been intensively explored. Only small gas pools of the stratigraphic type remain to be found.

The Arzgir-Prikumsk region is located mostly on land. Its southern part has not been explored intensively. The sedimentary sequence is highly promising, and almost all anticlinal traps contain pools. Most of the anticlines are small, however, and there is a tendency for their size to decrease in a seaward direction. Beneath the land, the most promising prospects are connected with stratigraphic traps, especially in Jurassic pinch-out zones. The figure of 1310×10^6 t for undiscovered resources in place (see Table 10) includes resources in Triassic sedimentary rocks; this estimate has to be decreased to 790×10^6 t for the portion of the platform cover that excludes the Triassic. However, realizing this potential would be rather difficult because of the great depth (more than 5000 m) of the most favorable Jurassic rocks. The offshore part of the region has a good sedimentary sequence and a thick Maykop seal, but the structural conditions are evidently inferior. We consider the analogy ratio to be about 0.7. Thus, resources in place for the offshore part of the platform cover of the Arzgir-Prikumsk region must be decreased to about 570×10^6 t. The main types of fields to be expected are gas-condensate and oil.

The Terek-Sunzha region is characterized by an extremely large concentration of resources in place. Specific resources there are much larger than in other regions. Although the Terek-Sunzha region has excellent exploration possibilities, especially in the Jurassic pre-salt sequence, such objectives lie mainly at depths greater than 5000 m. The potential of the geologically complicated zone of the Great Caucasus foothills is obscure because of lack of exploration data.

Oil and gas fields of the South Dagestan region are associated with structures of the folded slope of the foredeep. Although total discovered resources in place are rather small, specific resources are moderate. Although the volume of sedimentary rocks in the marine part of the region is not large, initial resources in place are thought to be very high. This is justified by the significant improvement in geological conditions toward the sea: (1) the faulting of anticlinal structures tends to decrease beneath the sea, (2) the Upper Jurassic sulfate-carbonate rocks that seal the Jurassic sequence are present and, (3) the thickness of promising middle Miocene sedimentary rocks increases significantly. Therefore, an analogy ratio of about 2.0 is reasonable. The greatest potentials of the land part of the region are mostly related to Jurassic sedimentary rocks, and potential fields are expected to produce mostly gas and gas-condensate.

Only the eastern portion of the Karpinskiy Ridge region is included in the area under investigation. The offshore part is characterized by good structural conditions and slightly thicker sedimentary cover. Discovery of the Kaspiyskoye oil field near the Caspian shore confirms the potential of the offshore part of this region. It is important to note that this oil pool occurs in Jurassic rocks that do not contain pools in other fields of the region. The analogy ratio is probably about 1.2. Oil and gas resources are expected to be about equal in amount.

It is difficult to assess the large Mangyshlak region. Except for the South Mangyshlak area, this region consists of the large Central Caspian monocline. The extremely high concentration of resources in place on the Zhetybay step can be contrasted with an absence of fields in the South Mangyshlak trough. Average specific resources are moderate. The offshore part of this region is highly attractive for exploration. Good structural conditions offshore of the Mangyshlak peninsula, improvement of hydrogeological conditions in the Cretaceous sequence, and appearance of thick Maykop shales that form the regional seal suggest an analogy ratio of about 1.3.

Of the total volume of sedimentary rocks in the region, 82,800 km^3 occur offshore at water depths greater than 400 m.

Only a small part of the North Apsheron region (Kusary-Divichinsk depression) lies on land, and this part does not characterize the entire region. Tertiary rocks are found onshore in unfavorable hydrogeological conditions and unconformably overlie folded Mesozoic rocks. In the offshore part of the North Apsheron region, however, thick middle and upper Pliocene sedimentary rocks occur. These rocks are highly productive in the neighboring South Caspian Basin, but their productivity in the North Apsheron depression is obscure. Although Table 10 lists an average figure for specific resources, this value is probably exaggerated. An analogy ratio of 0.7 seems suitable. A large part of the sedimentary sequence (49,800 km^3) occurs deeper than 7000 m. Of the sedimentary rocks occurring at depths less than 7000 m, 44,800 km^3 lie beneath water whose depth exceeds 400 m.

The last subsea area to be discussed occurs in the Karabogaz region. The land part of this region and Kara-Bogaz-Gol Bay have no apparent resource prospects, but these areas are not analogs of the marine area. The thickness of the platform cover increases in a seaward direction, and a large zone of pinch-out of Jurassic rocks appears very attractive for exploration. The average value for specific resources is probably appropriate.

The results of correcting the resource assessment in Table 10 by using analogy ratios are given in Table 11. Total resources in place beneath the sea, after correction, somewhat exceed the evaluation in Table 10. The corrected average value for specific resources is 14,450 t/km^3. Although the changes in the total values are not very significant, the evaluations for different regions are noticeably different.

We are not able to evaluate the Triassic sedimentary sequence in this fashion, because its thickness, composition, and distribution are not that well known. However, the oil and gas resources of these rocks would not change the total assessment markedly and might be significant only for individual regions, especially the land portions of the Arzgir-Prikumsk and South Mangyshlak regions.

The assessment of the North Ustyurt region is much less reliable, for only a small portion of the basin is included in the area under investigation. Although the source of the large resources of oil in place on the Buzachi arch is not clear, it might be in the Paleozoic-Triassic sequence. In spite of the good prospects for the offshore part of the region, it is unlikely that the same scale of oil accumulation has occurred beyond the crest of the arch. The analogy ratio could be about 0.7. A coefficient of exploration for the land is not available but is probably close to 0.7-0.8. The calculation of resources in place given in Table 12 is quite possibly understated. Therefore, significantly greater resources would be obtained for areas beneath the sea if the value for specific resources were calculated using only the volume of sedimentary rocks of the Buzachi region.

9.1.2 Reservoir-Volumetric Method

This method is based on concepts described in detail by Buyalov and Nalivkin (1979). It can be applied to a whole basin or to its separate parts.

Table 12 Resources in Place of the North Ustyurt Area Estimated by the Volumetric Method

Volume of the platform cover (km^3)	
Land	150,000
Sea	54,000
Discovered resources in place (10^6 t)	1,000
Coefficient of exploration	0.7
Specific resources (t/km^3)	9,500
Analogy ratio	0.7
Undiscovered resources in place (10^6 t)	
Land	430
Sea	360

Each sequence being evaluated is considered to be a self-regulating oil-gas-hydrodynamic system and to consist of hydrodynamically interconnected permeable complexes of rocks separated by impermeable seals. Each system is assumed to be in equilibrium and capable of accumulating a definite quantity of hydrocarbons. Application of the method to separate, relatively small regions requires using coefficients that qualitatively reflect the degree of petroleum potential. A given coefficient may vary significantly (0.3-3.0), and its selection is essentially subjective.

The relationship used for estimating resources in place is:

$$R = V_r \phi \gamma \times 10^9 \text{ t}$$

where:

R = resources in place (t),

V_r = volume of reservoir rocks (km^3),

ϕ = coefficient of concentration (fraction of unit), and

γ = average density of hydrocarbons (g/cm^3).

Statistical studies of 45 basins throughout the world (Vassoyevich et al., 1972) showed the coefficient of concentration to be 0.00012-0.00018 (average: 0.00015) for oil and 0.00018-0.00040 (average: 0.00035) for gas. For total hydrocarbons, 0.0003 is recommended by Vassoyevich et al. For the group of 25 basins to which the Middle Caspian Basin belongs, an average of 70% of the volume of reservoirs in subsurface conditions is occupied by gas and 30% by oil (Buyalov and Nalivkin, 1979). (Reservoirs that do not have impermeable seals are excluded from total-volume calculations.) The average density of hydrocarbons is taken as 0.85.

Although we did not have a complete set of maps for accurate calculation of volumes of reservoir rocks in the sequence, we could make reasonable evaluations. The major reservoirs in the Middle Caspian Basin are included in three oil- and gas-bearing complexes: the Lower-Middle Jurassic, the Lower Cretaceous, and the middle Miocene (in the foredeep). For the first complex, the volume of the Bajocian-Bathonian reservoirs was determined from Fig. 19. The volume of Lower Jurassic and Aalenian reservoir rocks does not exceed 10% of the Bajocian-Bathonian reservoirs in the Eastern Cis-Caucasus and is about 30% in the South Mangyshlak region. The volume of the Aptian-Albian reservoirs was determined from Fig. 21. The total volume of Neocomian sandstones (and probably Senomanian sandstones beneath the sea adjacent to the Mangyshlak peninsula) is not more than 10% of the Aptian-Albian reservoirs. Onshore Lower Cretaceous rocks of the Mangyshlak region are excluded from this calculation, as they are flushed by fresh water. The volume of middle Miocene reservoirs is evaluated from Fig. 25, where about 50% of the thickness belongs to this sequence. The average percentage of sandstones in the middle Miocene sequence is about 35% (Polster et al., 1972). Only reservoirs of the foredeep bounded by the 1000-m isopach were included in this calculation. Sedimentary rocks beyond this boundary have zero potential.

Results of the calculations are given in Table 13. Although this table does not include Upper Cretaceous sedimentary rocks that contain significant resources in the Terek-Sunzha and South Dagestan regions, this sequence may be a good prospect in the offshore portion of the South Dagestan region. Reservoirs in Upper Cretaceous carbonate rocks are commonly associated with zones of tectonic fracturing. Their volumes are comparatively small and would not influence total resource figures very much.

Comparison of the figures obtained by the reservoir-volumetric method with those obtained by the volumetric method shows satisfactory correspondence. Total resources in place of the Middle Caspian Basin assessed by the volumetric method are 22.5×10^9 t, only slightly less than the resources in place estimated by the reservoir-volumetric method.

The major difficulty of the reservoir-volumetric method is choosing the concentration factor. For large areas/volumes (reservoir rock volumes of more than 8000 km^3 for platform basins), the concentration factor is not a function of the quantity and size of pools (Buyalov and Nalivkin, 1979) but remains as calculated for the whole basin.

To verify the value for ϕ used for evaluating the resources in place of Table 13, we examined two regions. Sufficiently large volumes of reservoir rocks belong to the Lower-Middle Jurassic sequence of the land portion of the Mangyshlak region and to the Lower Cretaceous sequence of the Arzgir-Prikumsk region. The calculated concentration factor appears to be 0.00024 for the former and 0.00022 for the latter. Both figures are less than 0.0003, which was used for the Table 13 results. This slightly higher figure could explain the higher values for resources in place obtained using the reservoir-volumetric method as opposed to the volumetric method.

For the North Ustyurt region, we do not find sufficient correspondence between the two methods. As mentioned earlier, the data used in this report for the North Ustyurt Basin are inadequate. In particular, we do not know the exact coefficient of exploration, and it is obscure just which part of the basin has to be taken as the reference area for calculating the specific resources for the offshore portion of the basin. Finally, results using the

Table 13 Resources in Place of the Middle Caspian and North Ustyurt Basins Estimated by the Reservoir-Volumetric Method

Stratigraphic Complex	Volume of Reservoir Rocks (km^3)	Initial Resources in Place (10^9 t)
Middle Caspian Basin		
Lower-Middle Jurassic	47,300	12.0
Lower Cretaceous	31,300	8.0
Middle Miocene	32,000	8.2
Total		28.2
North Ustyurt Basin		
Lower-Middle Jurassic	12,600	3.2
Lower Cretaceous	19,600	5.0
Total		8.2

reservoir-volumetric method (see Table 13) seem to be greatly exaggerated for North Ustyurt. Unsuccessful exploration in the vast area beyond the Buzachi arch confirms this point of view. We will return to this problem in Sec. 9.1.3.

9.1.3 Volume-Genetic Method

This method of calculating resources in place estimates the volumes of oil and gas generated in a sedimentary sequence and the volumes that have migrated from it. (The method of calculating the amounts of oil and gas generated was discussed in Sec. 4.) For evaluating resources in place in poorly known regions, the volume-genetic method is more exact and requires fewer data than the volumetric method. The important advantage of this method compared to the methods discussed in Secs. 9.1.1 and 9.1.2 is that it provides an individualized approach to each resource evaluation area. Actually, all analogy methods fail to differentiate between petroleum-rich and petroleum-poor areas, a difference that is clearly found in nature. Because the volume-genetic method does not require comparison with analogs, it does not have this defect. The disadvantage of this method is its inability to determine what percentage of the total hydrocarbons generated have been accumulated in pools. Well-investigated basins exhibit accumulation factors of 1-5% for oil and 1-3% for gas.

The quantities of oil and gas that migrated from the two main productive complexes of the Middle Caspian Basin and the results of the volume-genetic calculation for accumulated gas and oil are shown in Table 14. The

Table 14 Oil and Gas Accumulation in the Sedimentary Sequence of the Middle Caspian and North Ustyurt Basins Estimated by the Volume-Genetic Method

Stratigraphic Complex	Total Amount of Migrated Hydrocarbons: Oil (10^9 t)	Total Amount of Migrated Hydrocarbons: Gas (10^{12} m^3)	Total Amount of Accumulated Oil (10^9 t): Upper Value (5%)	Lower Value (1%)	Average	Total Amount of Accumulated Gas (10^{12} m^3): Upper Value (3%)	Lower Value (1%)	Average
Middle Caspian Basin								
Bajocian-Bathonian	123.8	196.6	6.2	1.2	3.7	5.9	2.0	4.0
Aptian-Albian	195.7	267.0	9.8	2.0	5.9	8.0	2.7	5.3
North Ustyurt Basin								
Bajocian-Bathonian	4.8	9.0	0.24	0.05	0.15	0.3	0.09	0.18
Aptian-Albian	4.2	7.0	0.21	0.04	0.12	0.2	0.07	0.14

migrated quantities were measured from Figs. 28 and 29 and from Geodekyan et al. (1978b). Only the gas generated during Oligocene-Quaternary time (i.e., after deposition of the regional Maykop seal) is included in this calculation. Gas pools formed earlier were probably destroyed during geological history.

Some important conclusions can be drawn by comparing the results of Table 14 with those obtained for the same complexes by the reservoir-volumetric method (see Table 13). The close correspondence of the results obtained by the reservoir-volumetric method for Jurassic sedimentary rocks in the Middle Caspian Basin to the sum of the upper values of accumulated oil and gas in Table 14 is rather significant. It probably reflects the excellent conditions for conservation of oil and gas pools in the Lower-Middle Jurassic sequence beneath the basinwide Upper Jurassic seal. Conditions for preservation of pools in Lower Cretaceous sedimentary rocks were not as favorable. Here, conditions for preservation were determined largely by the distribution of Maykop shales, which are absent in the eastern portion of the basin. Accordingly, the value obtained for resources in place using the reservoir-volumetric method is close to the average value of accumulated oil and gas given in Table 14. Data in this table also provide a good explanation of the relatively low resource assessment for the North Ustyurt Basin by the volumetric method (see Table 12). The lack of oil and gas fields in the North Ustyurt region is apparently connected with a lower degree of transformation of dispersed organic matter and less oil and gas generation. Data from Table 14 confirm the views of Golov et al. (1979) that large oil deposits on the Buzachi arch had their sources in the underlying Triassic and Paleozoic sequence.

The assessment of resources in place by the volume-genetic method for various regions of the Middle Caspian Basin is given in Table 15. The regions (see Fig. 58b) were outlined on the basis of paleohydrodynamic data published by Geodekyan and Pilyak (1978). During most of its geological history, each region had a definite area of supply for hydrocarbons and possessed unique

Table 15 Resources in Place for Various Regions of the Middle Caspian Basin Estimated by the Volume-Genetic Method

Region	Generated Hydrocarbons				Accumulation Factor (%)				Resources in Place (10^6 t for oil; 10^9 m^3 for gas)			
	Oil (10^6 t)		Gas (10^9 m^3)		Jurassic		Cretaceous		Jurassic		Cretaceous	
	Jurassic Sequence	Cretaceous Sequence	Jurassic Sequence	Cretaceous Sequence	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas
Stavropol-Prikumsk	33,000	76,800[a]	10,000	105,800[a]	5	3	5[a]	2[a]	1,650	1,340	3,840[a]	2,120[a]
Terek-Sunzha	8,200		44,800		5	3			410	300		
South Dagestan-North Apsheron	15,000	14,200	29,200	19,400	3	2	3	2	450	580	430	390
Mangyshlak-Karabogaz	67,600	104,700	112,600	141,800	5	3	3	1	3,380	3,390	3,140	1,420
Total	123,800	195,700	196,600	267,000					5,890	5,610	7,410	3,930

[a]The Stavropol-Prikumsk and Terek-Sunzha regions cannot be distinguished for the Cretaceous sequence.

directions of migration of underground fluids. The Stavropol-Prikumsk region includes the Stavropol, Karpinskiy ridge, and Arzgir-Prikumsk regions shown in Fig. 58a, as well as the northwestern part of the Mangyshlak region. The Terek-Sunzha region is distinguished only in the Jurassic sequence; it merges with the Stavropol-Prikumsk region in the Lower Cretaceous sequence. The upper value for the accumulation factor for the Lower-Middle Jurassic sequence was taken for all regions except the South Dagestan-North Apsheron region. Conditions of accumulation and conservation of pools in most of these sedimentary rocks have been very good. For the North Apsheron region, middle values were taken because the greater depths of occurrence of Jurassic sedimentary rocks have presumably precluded preservation of pools. In the Cretaceous sequence, relatively good conditions of accumulation and preservation for oil have existed, especially in the western portion of the basin. These conditions deteriorate quickly in the eastern land areas. The conditions under the sea floor in the Mangyshlak-Karabogaz region are average for oil accumulation and preservation but poor for gas, which migrates more easily.

The volume-genetic method calculations demonstrate rather good correspondence with the reservoir-volumetric assessment for the Lower-Middle Jurassic sequence but are somewhat higher for the Lower Cretaceous rocks.

9.1.4 Discussion of Resource Estimates

The results obtained by the three methods are compared in Table 16. We consider the results obtained by the volumetric method to be the most reliable estimates in this report. This method is the most widely used and is the one best suited for comparisons between onshore and offshore resources. The other two methods independently confirm the volumetric-method results.

The resource estimates obtained by the volume-genetic method consider the potential only of the Mesozoic part of the sequence. Oil and gas generated in Tertiary beds would change the estimates mostly for the Terek-Sunzha, South Dagestan, and North Apsheron regions where the thick middle Miocene sequence occurs. The lower value of resources in place for the last two of these regions (see Table 16) obtained by the volume-genetic method apparently reflects the important role of the middle Miocene for resource assessment in this part of the basin. The significance of the very thick Maykop shales to hydrocarbon supply has not been emphasized enough. Although these beds contained huge quantities of dispersed organic matter, there were no reservoir beds in the areas of intense transformation of this organic matter. Therefore, conditions of primary oil and gas migration were extremely poor. It is true, however, that the total amount of oil and gas generated in the Tertiary sequence will not change the overall resource assessment significantly. We believe that the corrected value, based on adding in the Tertiary sequence, will be closest to the estimate obtained by the reservoir-volumetric method.

As shown in Table 16, approximately 75% of the undiscovered resources of the Middle Caspian Basin are located beneath the floor of the Caspian Sea. Exploration beneath the land will be at depths of 4000-7000 m, and new discoveries will be related mostly to stratigraphic traps or traps occurring in complicated structures. Although exploration of Triassic sedimentary rocks could be successful, significant changes in the total resource estimate are

Table 16 Petroleum Resources in Place for the Middle Caspian and North Ustyurt Basins (10^6 t)[a]

	Method		
	Volumetric	Reservoir-Volumetric	Volume-Genetic
Middle Caspian Basin Total Resources in Place	22,510	28,200	22,840[b]
By region			
Stavropol, Arzgir-Prikumsk, Karpinskiy Ridge, and Terek-Sunzha	8,430		9,660[b]
South Dagestan and North Apsheron	5,290		1,850[b]
South Mangyshlak and Karabogaz	8,790		11,330
By stratigraphic sequence			
Jurassic		12,000	11,500
Cretaceous		8,000	11,340
Tertiary		8,200	
By location			
Onshore	10,420		
Offshore	12,090		
By exploration			
Discovered	6,500	6,500	6,500
Undiscovered	16,010	21,700	16,340[b]
Onshore	3,920		
Offshore	12,090		
North Ustyurt Basin Total Resources in Place	1,790	8,200	500
By location			
Onshore	1,430		
Offshore	360		
By exploration			
Discovered	1,000	1,000	1,000
Undiscovered	790	7,200	
Onshore	430		
Offshore	360		

[a]The oil equivalent for gas is taken to be 1 t of oil equals 1000 m^3 of gas.

[b]Excludes the Tertiary sequence.

not expected. Triassic sedimentary rocks usually do not contain persistent reservoir beds and good seals, they are strongly faulted, and conditions for preservation of pools are poor. Finally, exploratory drilling in the Triassic sequence is not expected to be successful (Krylov, 1971). New onshore fields probably will be of small to average size and predominantly of the gas-condensate type.

The offshore part of the basin possesses comparatively large resources, although much of it will be difficult to explore because of the thick sedimentary sequences over the main productive complexes and because of great water depths. Formations beneath the large central part of the Caspian Sea are almost totally unexplored, and only a few regional seismic profiles have been completed. However, some areas near shore have been explored to a much higher degree and have displayed excellent potential. These areas are discussed in Sec. 9.2.

Table 16 shows an absence of correspondence in the three resource assessment values for the North Ustyurt Basin. Resources in place estimated by the reservoir-volumetric method are much larger than the other two and seem exaggerated when the lack of discoveries beyond the Buzachi arch is considered. We suspect that the main defect of this method has played a role here. The method tacitly assumes that every basin is sufficiently supplied by hydrocarbons and that the value of resources is limited by the capacity of the hydrodynamic system. In the North Ustyurt Basin, however, the lack of hydrocarbons is clearly demonstrated by the volume-genetic method. The higher value for discovered resources in place than for total resources suggests an external source of hydrocarbon supply, which was mentioned as a possibility in Sec. 9.1.3. More significantly, however, this discrepancy demonstrates the weakness of the volume-genetic method in estimating petroleum resources, at least with respect to separate stratigraphic complexes. For example, evaluating the offshore potential of the Buzachi peninsula is difficult, because it is impossible to know if this area was supplied by hydrocarbons from the Triassic and/or the Paleozoic sequence, as is the case on the Buzachi arch. Pending more detailed investigations, the value obtained by the volumetric method is considered to be a reasonable though provisional assessment.

9.2 POSSIBLE ZONES OF FUTURE EXPLORATION BENEATH THE CENTRAL CASPIAN SEA

Structural and stratigraphic conditions favorable for oil and gas accumulation beneath different parts of the Caspian Sea were compared with adjacent onshore areas in Sec. 9.1.1. Figures 59 and 60 compare the conditions of oil and gas generation beneath the sea with those of the bordering land areas. These maps show the total volume of oil generated in the Bajocian-Bathonian and Aptian-Albian sequences during their geologic history, the time of the main phase of oil generation, and the areas with intense gas generation in the Cenozoic (i.e., after the beginning of the Maykop sedimentation that created a thick impermeable seal throughout the region). These figures clearly show the shift through time of the zone of most intense oil generation (main phase) as it moved from the platform edge to the northeast. They also indicate that conditions of oil and gas generation in the offshore part of the Middle Caspian Basin were generally more favorable than those on the bordering lands. The maps also show zones of potentiometric lows that existed during the greater part of the geological history of the basin. From

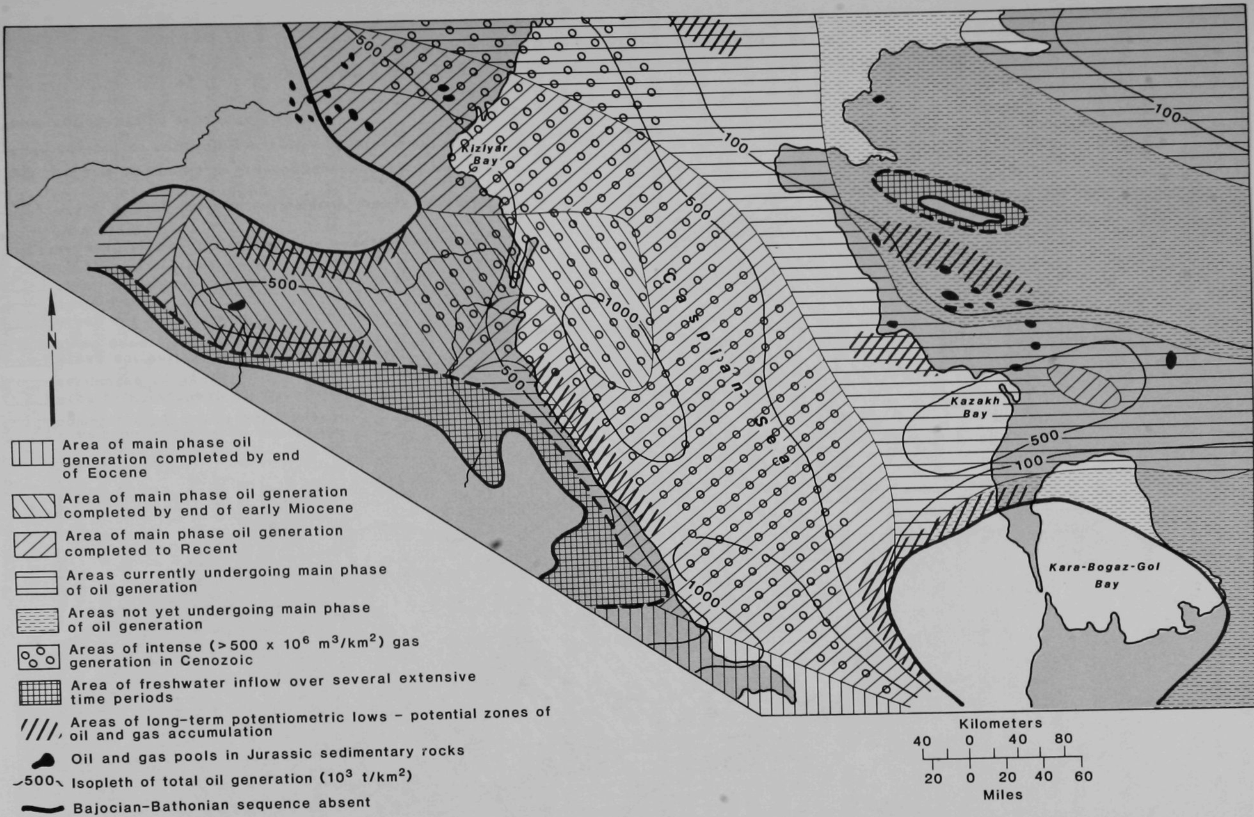


Fig. 59 Oil and Gas Genetic Zonation for the Bajocian-Bathonian Sequence (Source: After Geodekyan et al., 1978a)

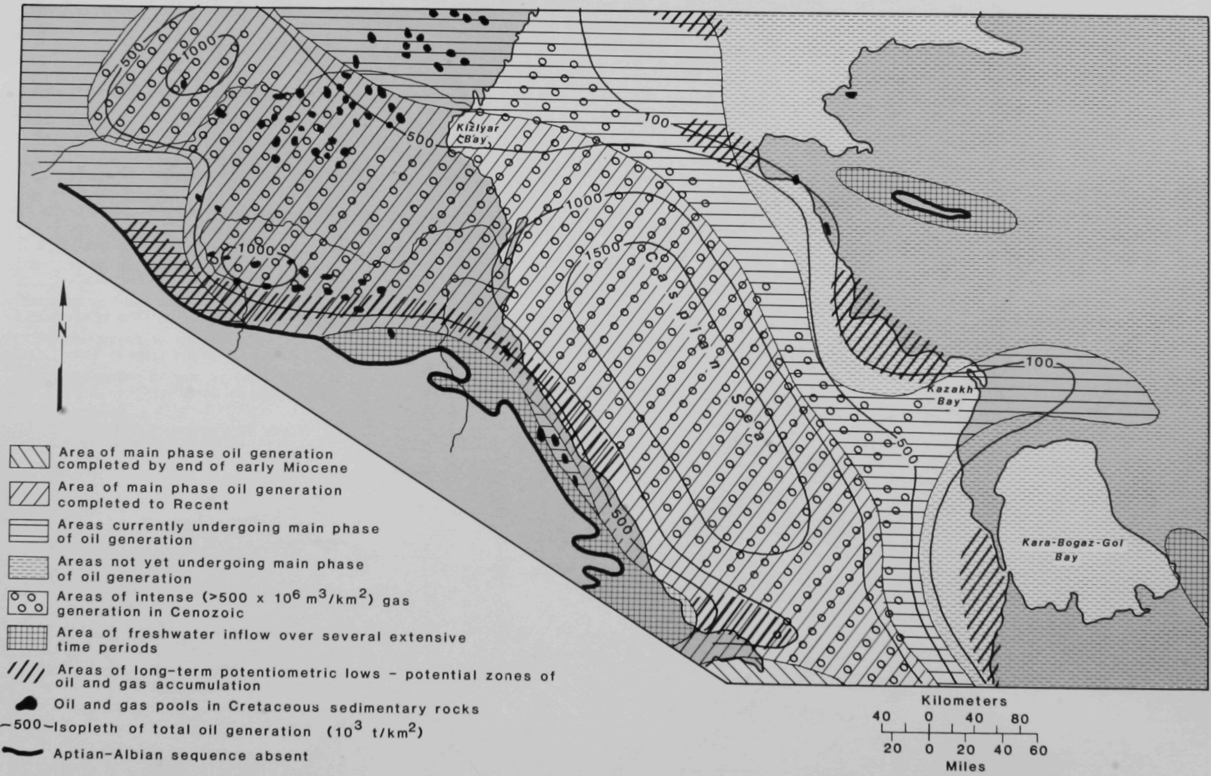


Fig. 60 Oil and Gas Genetic Zonation for the Aptian-Albian Sequence (Source: After Geodekyan et al., 1978a)

hydrodynamic and oil migration points of view, these lows were the most favorable zones for accumulation of hydrocarbons. The zones that are located offshore are discussed in more detail immediately below.

Two very favorable zones for exploration occur offshore of the South Mangyshlak region. The first zone lies on the plunging seaward continuation of the Mangyshlak zone of uplifts (see Fig. 60), where the Tyub-Karagan swell projects about 80 km offshore. The offshore part of the swell is complicated by two local structural culminations. The onshore part of the swell contains an exhausted oil pool (Tyubedzhik field), and there have been oil shows from the Kusaynik field near the shore. The thickness of the sedimentary cover increases seaward, and the main productive layers dip beneath younger Paleogene sedimentary rocks. The southern branch of the Central Mangyshlak zone of uplifts, the Bekebashkuduk swell, continues offshore and contains a large anticlinal structure, Aralda-more. Two other local structures are inferred (Yeremenko et al., 1974). The Aralda-more field is considered to be one of the most important objectives for exploration in the near future (Lebedev, 1978), although more detailed geophysical studies are needed prior to drilling. The increasing thickness of the platform cover, the supposed improvement of reservoir properties in the Jurassic sequence, and the good position of this area relative to the oil-collecting area in the Middle Caspian Sea all suggest that the chances for significant petroleum discoveries are rather high. The discovery of oil pools is more probable than gas pools, and potential resources are likely to be connected not only with Jurassic rocks but also with the Lower Cretaceous sequence. The Lower Cretaceous consists of marine sedimentary rocks with good reservoir properties, which creates favorable conditions for exploitation.

The second structure offshore of the South Mangyshlak region that has been considered an extremely good prospect is the Peschanomys uplift. This structure was the first and most important objective for exploration in the central Caspian Sea. Several local anticlines were found to complicate the Peschanomys uplift, most of which are associated with a deep fault that separates the uplift from the Kazakh depression (see Sec. 2.2.3). The largest of the anticlines is Rakushechnoye-more, with dimensions of 29 km by 15 km in plan and about 500 m in height (Yeremenko et al., 1974). The structure was found by seismic surveying in 1963; it had been outlined sufficiently to permit drilling by 1973 (Nikolayeva, 1974). Deep drilling began in 1973 but failed to establish commercial production. The most detailed seismic and drilling activities in the central Caspian Sea are currently concentrated in this region. Good reservoir beds and shows of oil have been found. The rather small amount of drilling to date suggests that this feature has not been adequately tested. Therefore, it is premature to downgrade the importance of this structure. On the other hand, the large, deep fault bordering the Peschanomys uplift on the south may have interfered with oil accumulation. This fault developed continuously from at least Jurassic time and could have prevented oil migration from the major oil collecting areas in the central Caspian Sea and Kazakh Bay (see Figs. 9, 12, and 28). The main oil generation and migration in this region coincided with displacement of up to 1 km of the Jurassic and Lower Cretaceous layers along the fault. Therefore, the down-thrown side of the fault may be an excellent fault-trap prospect. Because local closures have not been found on the down-thrown side of the fault, it is unlikely that exploration for hidden, fault-trap pools at depths of about 3500-4500 m will be undertaken in the near future.

Drilling on the onshore part of the Karabogaz arch has not disclosed any shows of hydrocarbons, and only noncommerical accumulations of gas were found on the north flank of the arch (Orudzheva et al., 1978). However, a large, offshore pinch-out zone in the Jurassic and partly in the Lower Cretaceous sedimentary rocks is located favorably as far as directions of oil migration are concerned (Geodekyan and Pilyak, 1978). This part of the offshore area has not been well studied. Because the water depth exceeds 50 m and increases rapidly to the west, drilling probably will not be undertaken in the near future.

The region offshore of South Dagestan is the most interesting area for exploration beneath the western part of the central Caspian Sea. In 1972 the Inchkhe-more oil field, with a pay zone in the middle Miocene sequence, was found here (Yusufzade, 1977). The onshore part of the region contains several oil and gas fields of small size (see Fig. 32 and Table 3) associated with two zones of folding. Production is from Cretaceous and Tertiary sedimentary rocks. The Middle Jurassic sequence, which is separated from the productive interval by a significant angular unconformity, is overlain by Barremian rocks and does not contain pools (Gadzhiyev, 1974). The eastern flank of the eastern anticlinal zone is complicated by a deep fault that separates the folded Caucasus foothills from the axial area of the foredeep. Displacement on the fault exceeds 1500 m. Along this fault the eastern zone is overthrust on the coastal area. A chain of anticlines, the so-called Maritime zone, has been discovered on the lower plate of the fault by geophysical investigations. The above-mentioned Inchkhe-more structure also is located there. The chain is characterized by thickening of the productive Tertiary sequence and the appearance of the Upper Jurassic regional seal. It is located extremely favorably relative to oil-generating areas of the foredeep and the Cis-Dagestan downwarp (Geodekyan et al., 1979). A fourth line of anticlines, believed to lie to the east of the Maritime zone, has been inferred from geophysical data (Gadzhiyev, 1980). This region is now an area of exploration and will undoubtedly produce discoveries in the near future. The middle Miocene and Upper Cretaceous sequence will be the first exploration objective. However, discoveries of very large or giant fields are scarcely probable because of the relatively small size of the anticlinal features.

Finally, beneath the northern part of the central Caspian Sea, the uplifted zone between the Buzachi arch and the Karpinskiy ridge (see Figs. 59 and 60) may be considered a favorable area for exploration in coming years. Discoveries in the onshore Buzachi arch undoubtedly have increased interest in this area. Although several structures (Morskoye, Rakushernoye [northern], Kulaly, etc.) were found here, the petroleum resource potential of this region is apparently lower than for other regions (Lebedev, 1978).

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